

SKYLAB₅

Our First Space Station

NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION



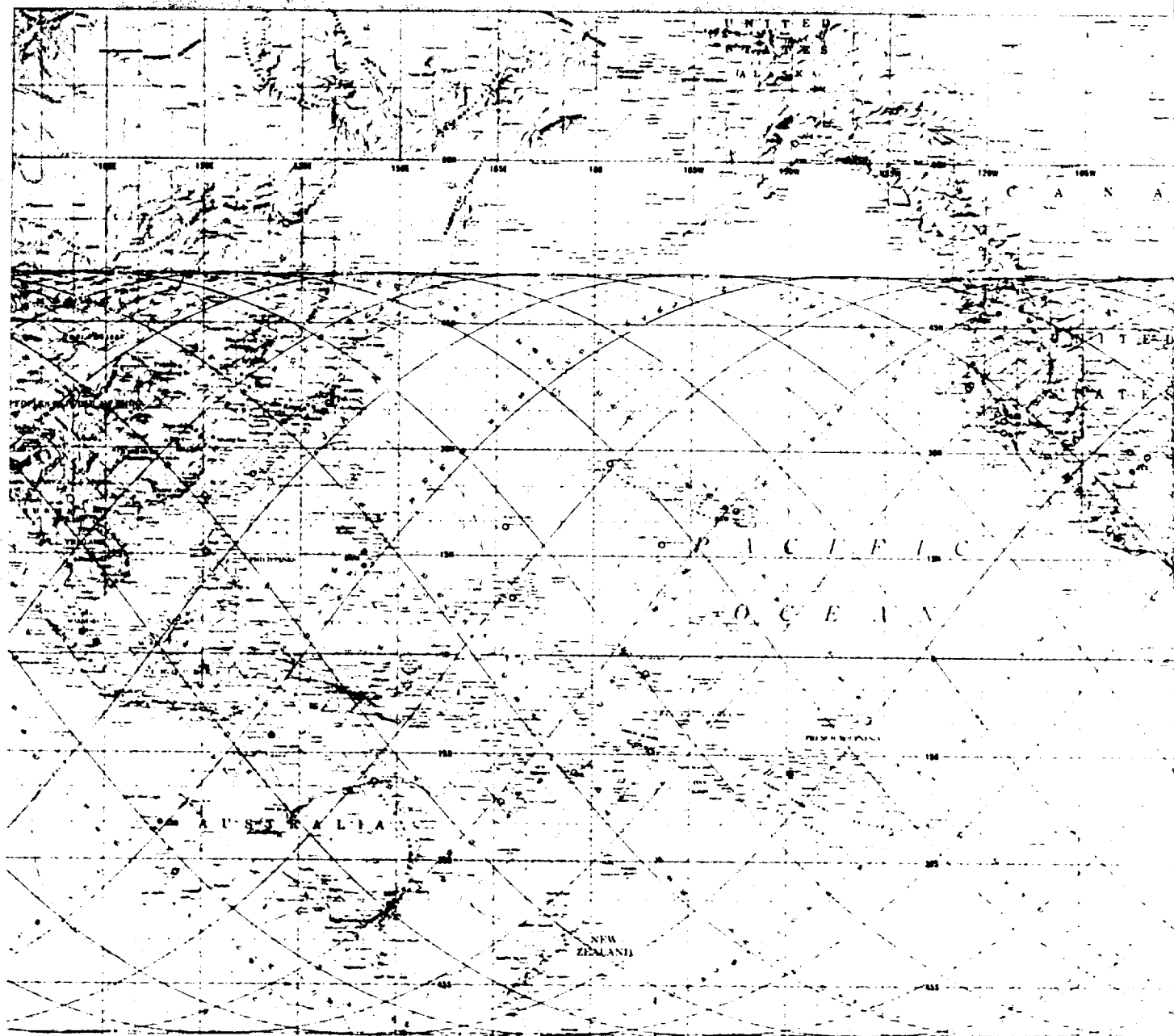
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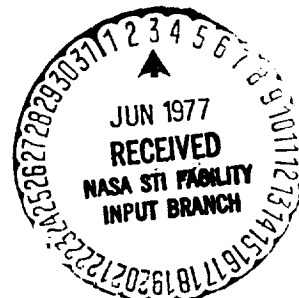
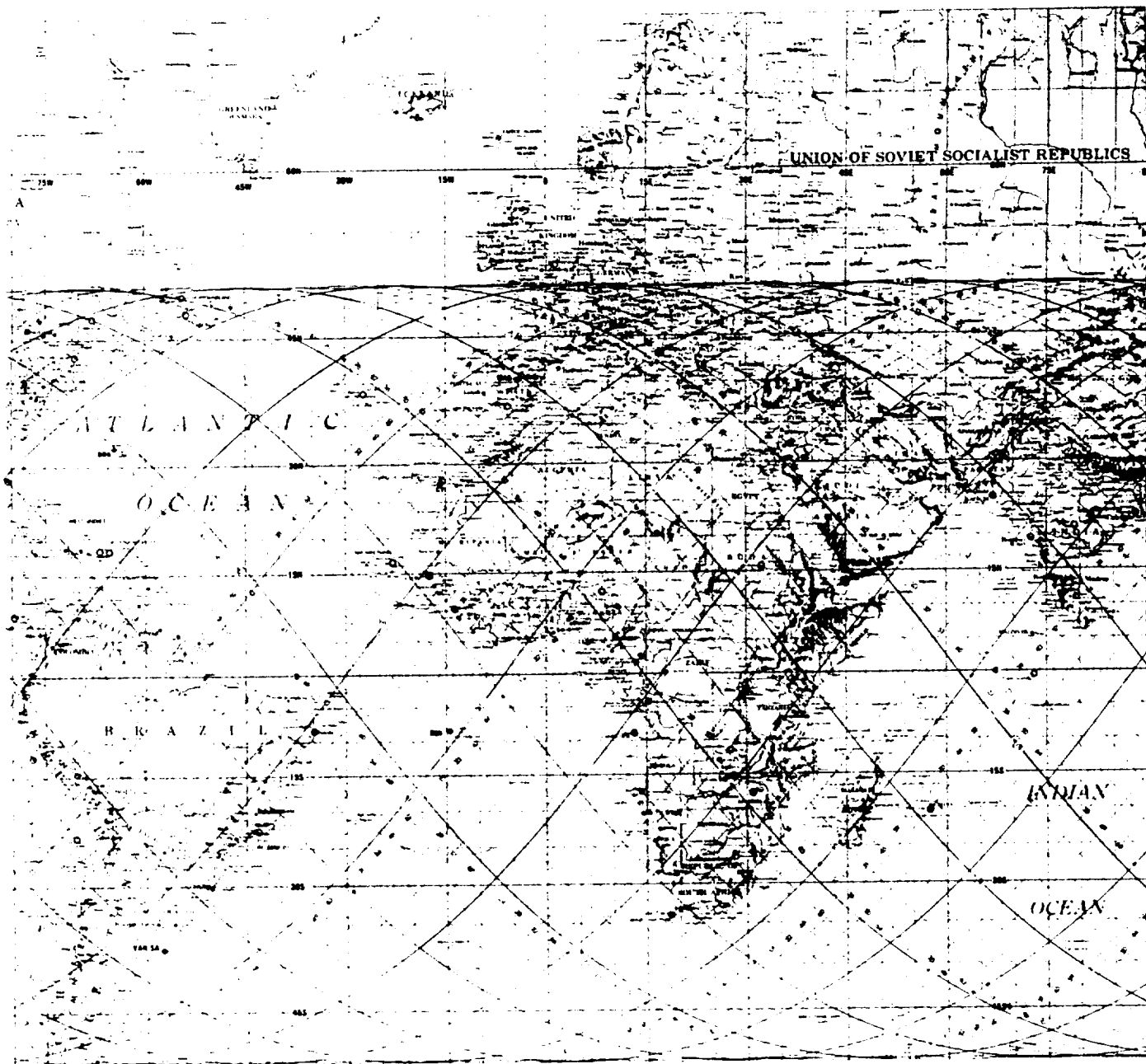
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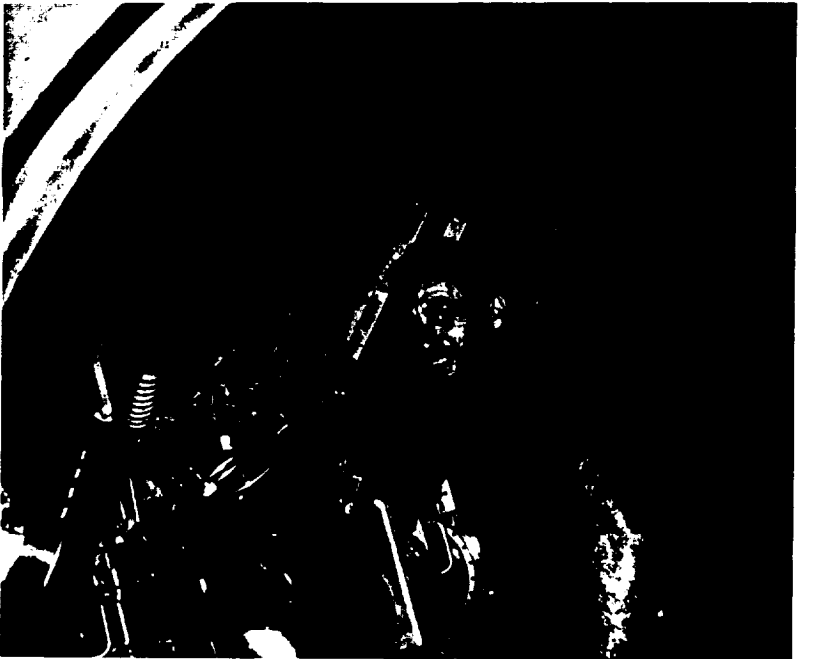
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Our First Space Station

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Prepared by
George C. Marshall
Space Flight Center

Skylab provided a laboratory where materials processing
occurred beyond the reach of gravity . . .



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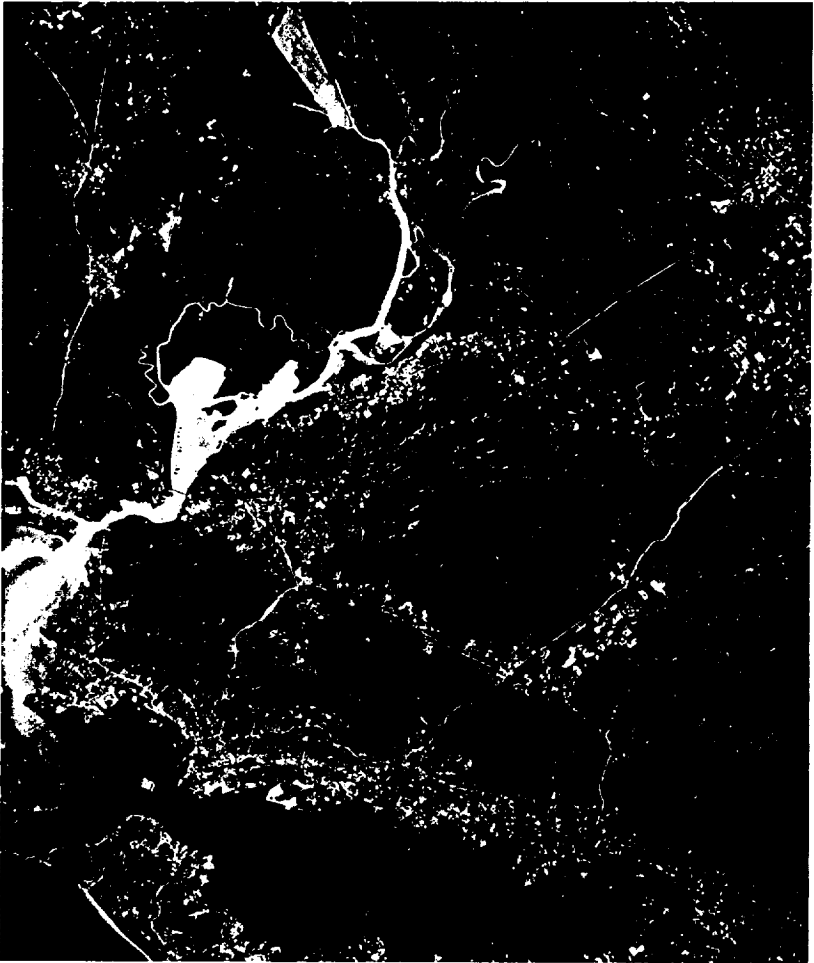
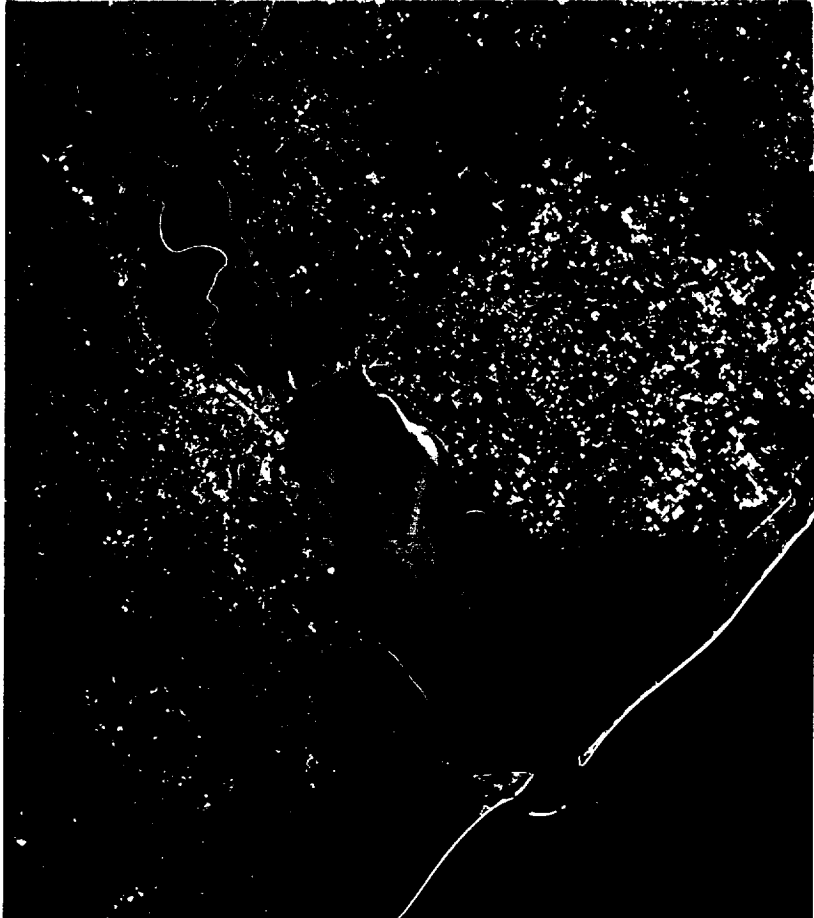
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looked inward to Earth to study its vast resources . . .



FOREWORD

The initiation of our first space station program in 1966 based on hardware developed for other programs was a modest beginning for what was to become a mission of unparalleled scope once flight operations began. Bold in concept, the program demanded innovation and ingenuity during its design, development, and test phase as the required flight hardware became more firmly defined, and the planned flight operations came more clearly into focus. Experience and knowledge gained from earlier space programs provided a solid foundation on which to build, but the Skylab program was truly making new pathways in the sky and pioneering on a new frontier.

The vast accomplishments of Skylab—in solar and stellar astronomy, in the detailed study of our planet from the incomparable vantage of orbit, in using the exciting new laboratory tool of weightlessness, and in proving that man can work productively in space for extended periods—are almost too profound to grasp. The data on solar physics contains new and valuable information on the Sun's corona and the solar winds and opens up new concepts to be explored in future solar astronomy programs. In the area of technology, the data from Skylab's space processing experiments opens a completely new dimension in the field of materials processing. Crystals grown in Skylab have shown structural perfection, uniform-

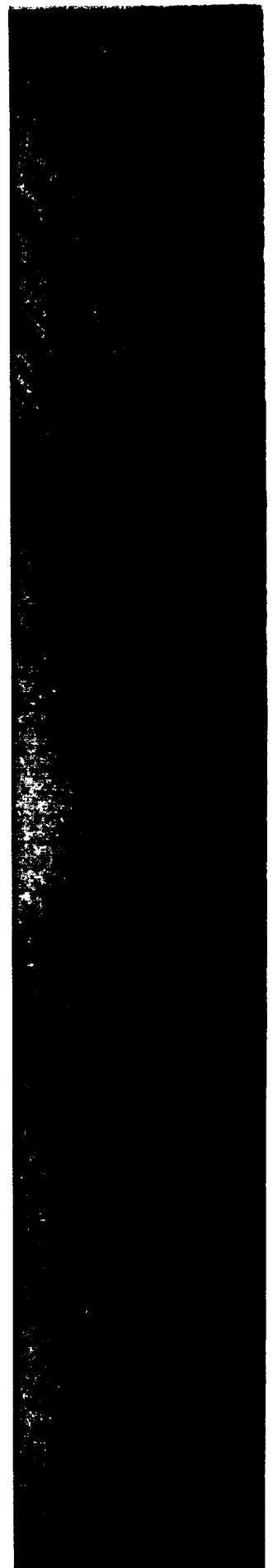
ity, and relative size not attainable on Earth, and the experiments performed with metal alloys and composites have aroused keen interest in future possibilities of materials processing under conditions of weightlessness.

In my opinion, the finest accomplishment of Skylab was the demonstration of the uniqueness of man in space in solving problems and overcoming obstacles in the face of extreme adversity. Shortly after liftoff of the unmanned Skylab space station, serious problems developed starting with the loss of the micrometeorite shield, which resulted in a total loss of heat balance in the workshop and a substantial loss in the solar power generation system. Facing what could have been a total loss of our first space station, the Skylab team—both the flightcrews and the thousands of engineers, technicians, and support personnel on the ground—converted these awe-inspiring challenges to opportunities that demonstrated man's role in space far beyond the most ambitious dreams of most space planners.

The legacy of the Skylab program to be passed on to planners and operators of future manned space programs is best stated in two words: "Can do!"

ROCCO A. PETRONE

observed the Sun and the heavens beyond with a clarity
never before possible . . .



PREFACE

In this introductory volume to a series of reports on the Skylab program, it gives me great pleasure to acknowledge not only the many achievements but also the extraordinary efforts of the teams of people who made the achievements possible. As Director of the program during its 8 years of planning, preparation, and completion, it was my privilege to work with as fine and dedicated a group of people in the research centers and in industry as it would be possible to assemble for any endeavor. The spirit of which I speak extended throughout the entire program but reached its culmination in the enthusiastic and imaginative solutions to the many mechanical problems which—without quick and workable solutions—would have resulted in mission failure.

The ability of the ground and flight crews to react rapidly to repair or work around crippling problems was one of the bonuses of our first space station. The crews demonstrated that, in space as well as on Earth, man with his intelligence and perseverance can do the near impossible. And if there was ever a case to argue the need for man in space, Skylab provides that example.

Those who labored in the program were dedicated to the thought that space was there to be used as well as to be explored, and they developed a set of tasks to prove their hypotheses by demonstration. That they were right has now been proved conclusively, for the results of Skylab have far exceeded expectations.

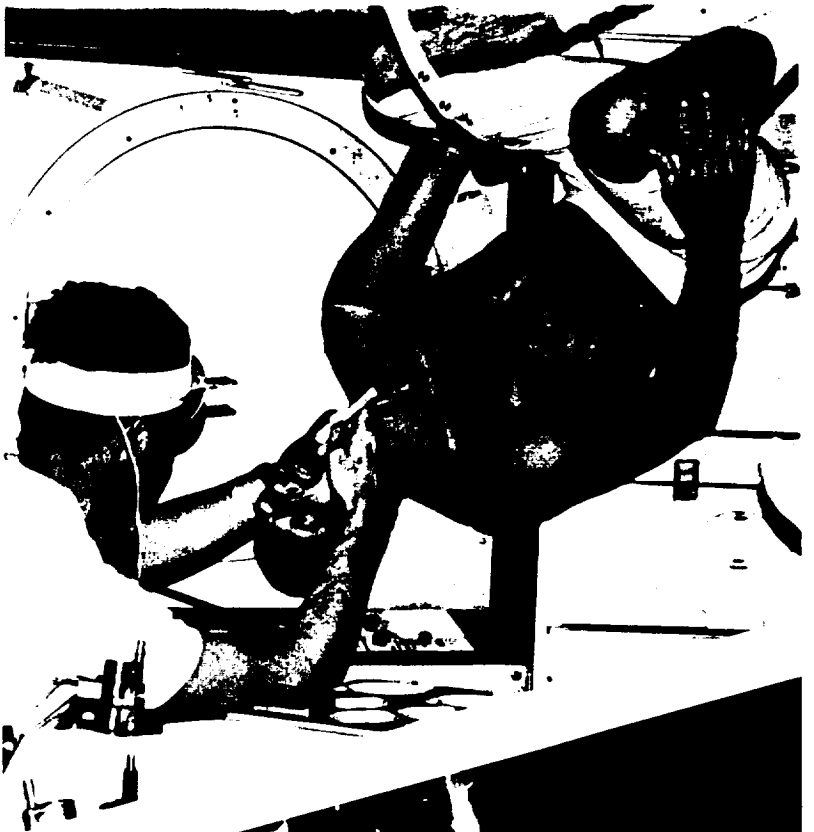
It may even yet be too early to catalog all the achievements of the Skylab mission and its people,

but one point is clear: a multidisciplinary manned space station is not only practical, but can be highly productive. There are many facets to this conclusion, but three stand out. First, the men worked well in space, actively enjoying the experience of living in orbital weightlessness; second, it was possible to maintain essentially normal operations of this immensely complex vehicle, even in the face of a number of equipment malfunctions; third and most important, the crews produced a large volume of very high quality data in many fields, more than fulfilling the hopes on which the experiment program was based.

It is impossible to single out any one area as the most important result of the Skylab missions. Skylab has served almost every scientific and technological discipline that could benefit from its special characteristics: the broad view of Earth, the freedom from atmospheric interference with observations of the Sun and stars, the absence of gravitational effects, and the presence of trained men to make scientific observations and to operate the complex equipment. Additionally, Skylab established a broad base of factual data on which to base the design of future space systems and the planning of future operation in space. Even more important, it has demonstrated that man has significant work to do in space.

November 5, 1976

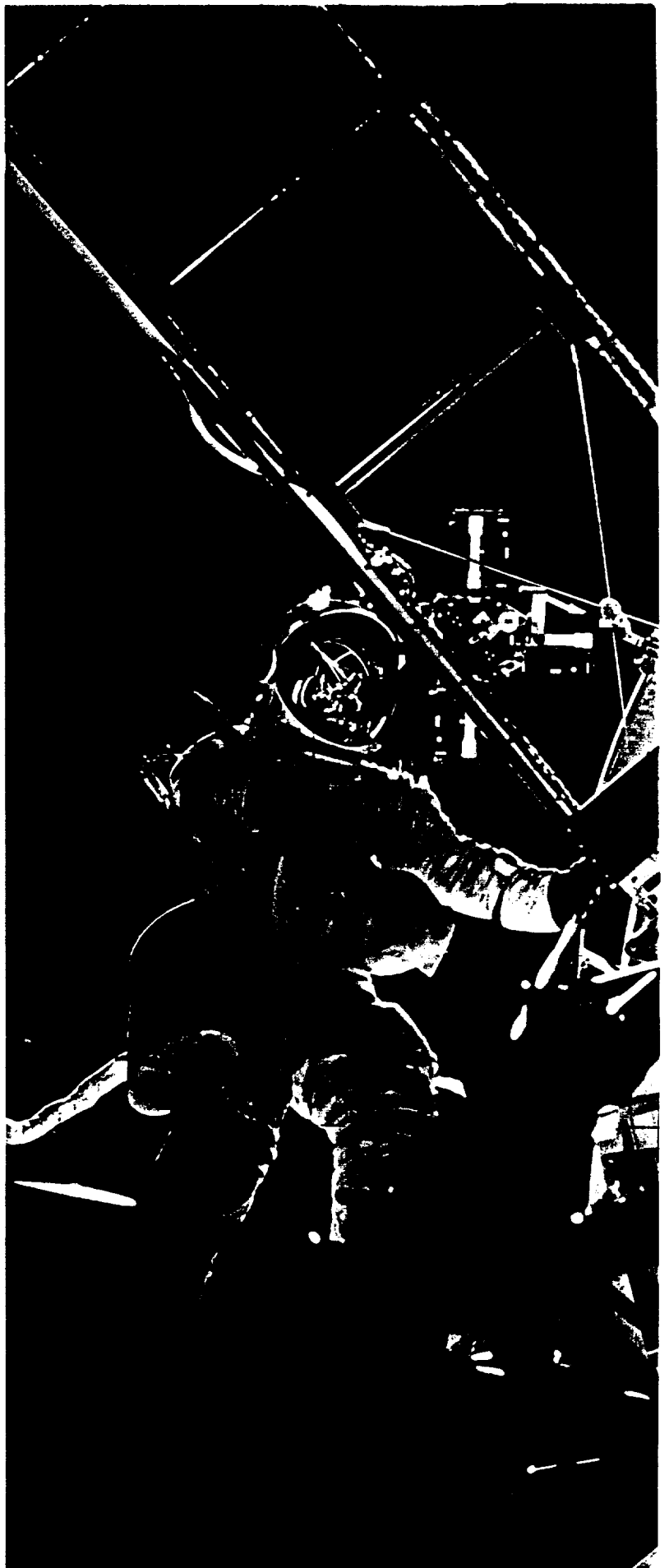
WILLIAM C. SCHNEIDER
*Office of Space Flight
National Aeronautics and
Space Administration*

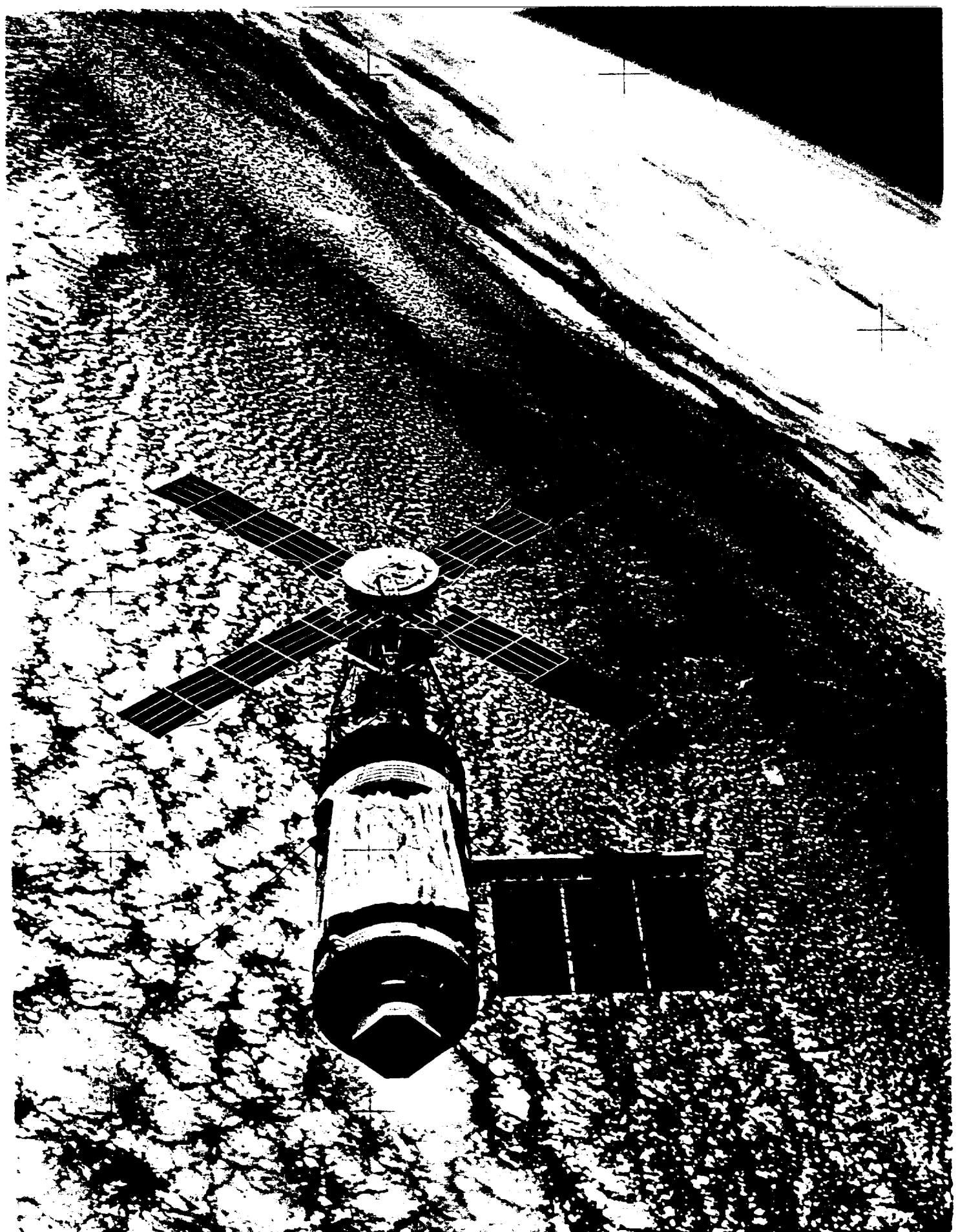


observed the effects of a gravity-free environment on life processes . . .



and, most important, provided a wealth of data on the capability of man to live and do useful work for long periods in space.





1

The Challenge of Skylab

Skylab was the United States' first space station—and much more.

It was, of course, a complex and complete orbiting home and scientific laboratory, where nine highly trained astronauts lived and worked in teams of three in shirtsleeve comfort. But it was also a program of unparalleled scientific scope which continues to yield highly valuable information about the universe and life within it.

Skylab was a comprehensive program of scientific experimentation that revealed heretofore unknown information about man's capability to withstand long periods of weightlessness, about the adaptability of other living creatures to the space environment, and about life itself.

It produced a vast study of the Earth's crust; of the oceans and of life beneath their turbulent surfaces; of ranging mountains, lush forests, and desert wastelands; and of crops, weather, and changes in environment created by man.

It permitted a revealing study of the great star Sun, unparalleled in scope and unmatched in results.

It gave an intimate look into the universe, a firsthand study of comets, meteors, the planets, and the stars.

It included a factory where men manufactured alloys, grew perfect crystals, and learned to work in space.

Involving scientists from 28 nations, Skylab demanded the highest degree of cooperative effort from the world's scientific community. Scientists,

engineers, and technicians worked, observed, cataloged, and analyzed data on Earth while Skylab orbited overhead, its crew making related observations and scientific measurements or conducting experiments. And when their work was finished, this team was able to correlate the data obtained from both sources, thus refining the scientist's capability to more accurately observe and predict phenomena on Earth.

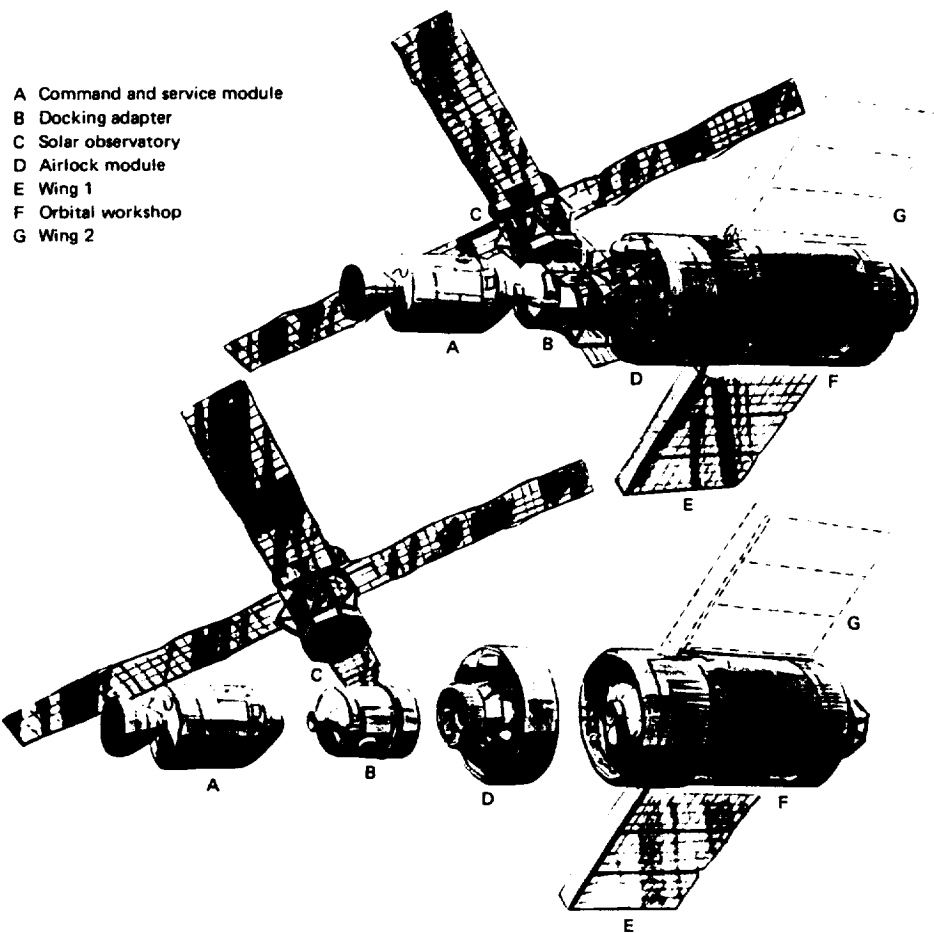
Skylab was excitement, high adventure with all the drama that could be packed into its three manned flights, totaling nearly half a year. It was conquest, of manmade hardware, of difficult and challenging environment, and even of ideas.

And it was a severe test of man's capability to analyze, solve problems, and make innovative repairs in a hostile and unforgiving environment.

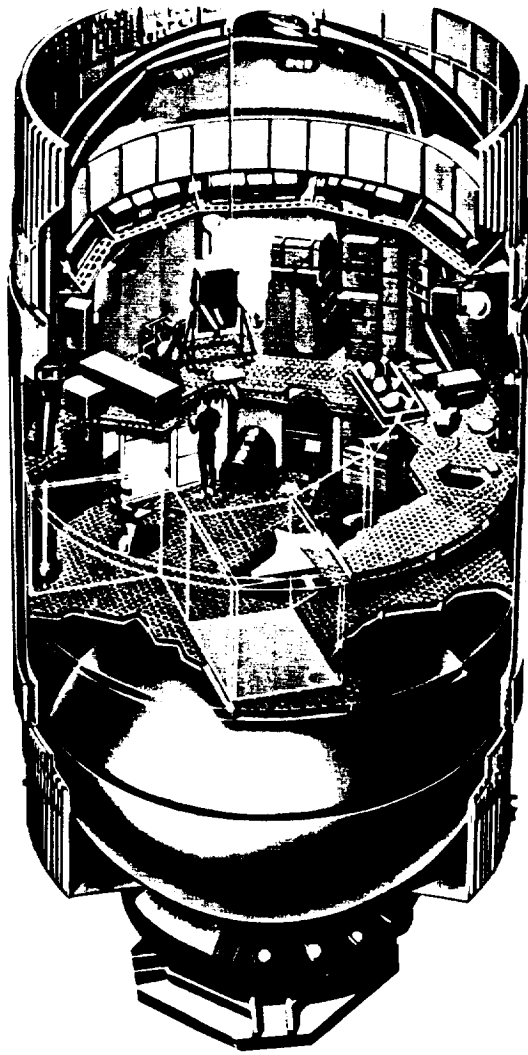
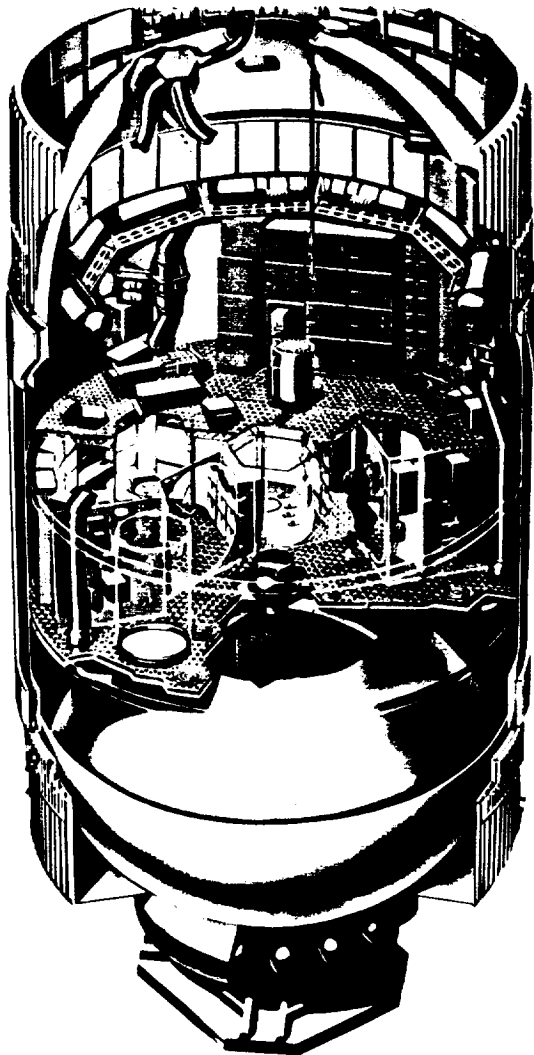
Skylab was ingenuity. The program was initiated with hardware developed for other programs, modified for this space odyssey, and supplemented by items designed specifically for the conduct of its unique mission.

And Skylab was innovation. It was men challenging and overcoming the formidable obstacles placed in their path by malfunctioning equipment, refusing to bow to adversity, even in the face of great danger. It was the dogged determination of men to achieve their goal.

Skylab's success proved many things. Chief among these is man's capability not only to sustain long periods of weightlessness but to live and work effectively in the space environment. And the



This drawing shows the wings and the five major assemblies of Skylab: workshop, airlock, docking adapter, solar observatory, and command and service module. The Apollo command and service module was the logistics vehicle, docking at the forward end of the docking adapter, which housed many of the experiments and provided a docking port. The airlock connected the docking adapter and the workshop; the latter provided the living and working quarters for the crew. The solar observatory was mounted on a structure above the docking adapter.



Two cutaway views of the orbital workshop showing details of the living and working quarters.

program provided a vast amount of scientific data which scientists will be analyzing for many years.

Our First Space Station

Five major assemblies, clustered together, made up the orbiting space station called Skylab. The largest of these was the orbital workshop, which housed the crew quarters and a major experiment area.

The airlock module, attached to the forward end of the workshop, enabled crewmembers to make excursions outside Skylab, and the docking adapter, attached to the forward end of the airlock module, provided the docking port for the Apollo command and service module.

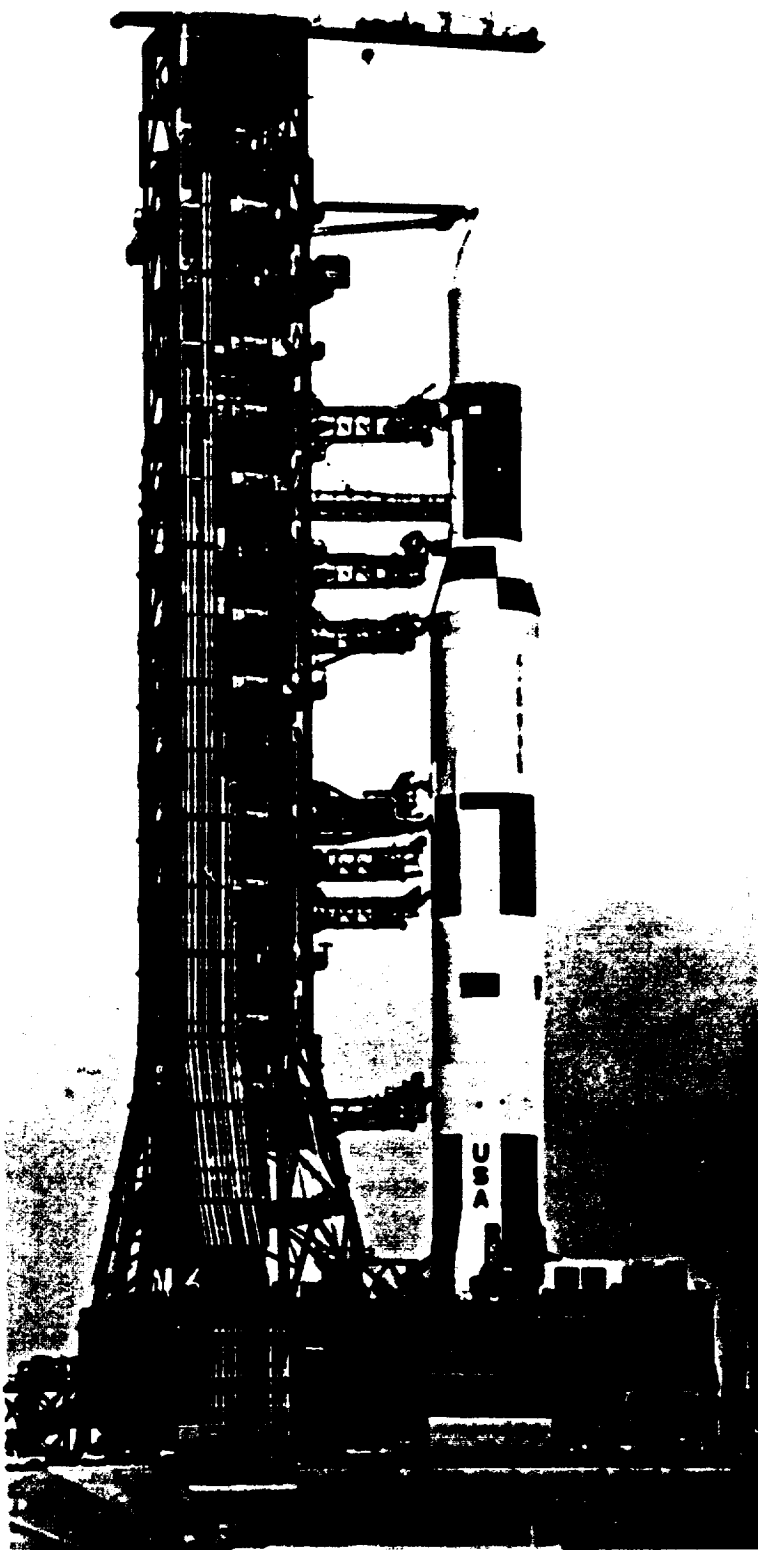
The Apollo Telescope Mount (ATM) was the

first manned astronomical observatory designed for solar research from Earth orbit.

Together, the five assemblies weighed nearly 100 tons. Their volume was about that of a small three-bedroom house. Most of the usable volume was in the workshop, where the astronauts lived and worked.

The Skylab Missions as Planned

Four separate launches, one unmanned and three manned, were planned for the Skylab program. Initially, the manned missions were programmed for 28, 56, and 56 days, respectively, but the second and third crews stayed longer than planned. This greatly enhanced the program's scientific value.



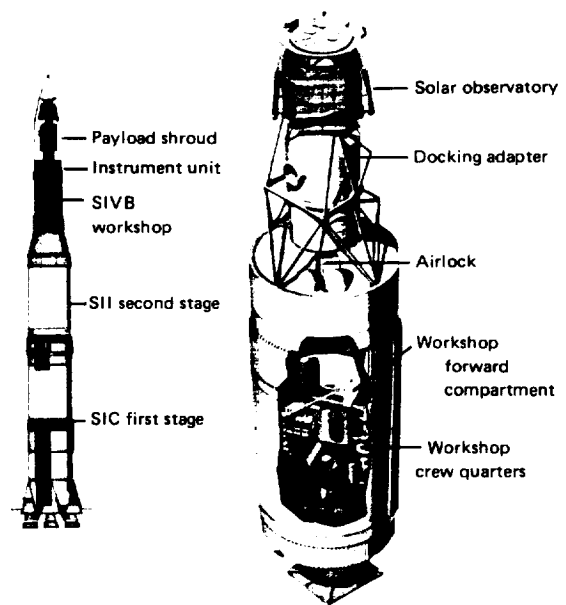
The Saturn V rocket stands poised on Pad A of Launch Complex 39 at the Kennedy Space Center. Its passenger was Skylab, our first space station.

Plans called for launching the Skylab cluster, encased in its aerodynamic shroud, on a two-stage Saturn V launch vehicle. After arrival in orbit, with the shroud then jettisoned, the solar observatory would be rotated to face the Sun, and its solar array would be extended. Following this, the solar array of the workshop would be extended.

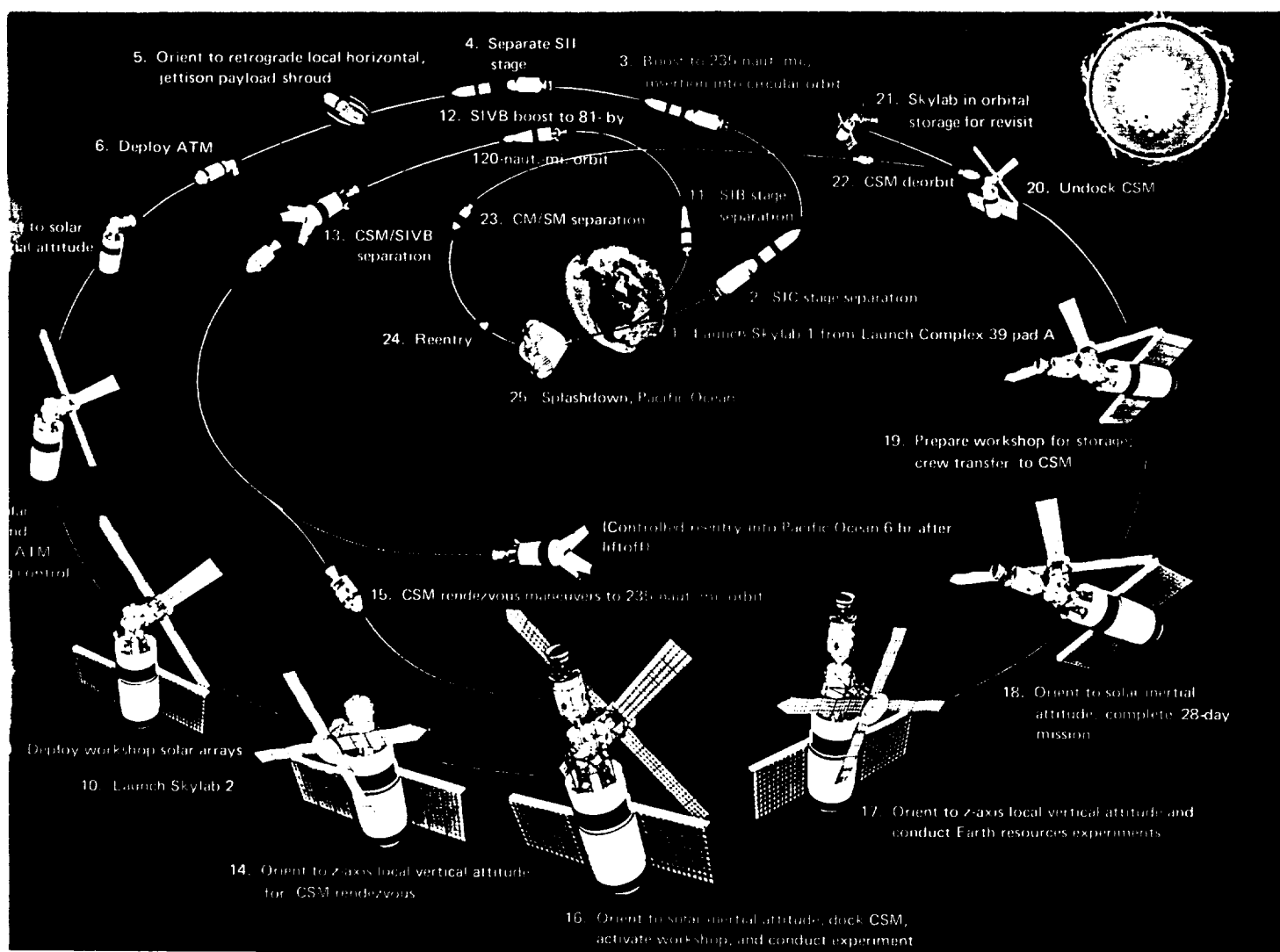
Then the micrometeoroid shield, which fitted snugly around the workshop during launch, would be extended outward. This shield was designed not only to protect the workshop from micrometeoroids but it also provided protection from the powerful rays of the Sun, thus holding inside temperatures to a habitable level.

The unexpected tearing off of this shield from the workshop shortly after launch and the damage to the workshop solar array created the drama marking the early days of Skylab.

About 24 hours following the unmanned launch, the manned command and service module with its crew of three astronauts was to be launched by a Saturn IB. This crew was to dock with Skylab and enter and activate the systems for a manned mission of 28 days. During this period, crewmen



Ready for launch, Skylab was encased in a massive aerodynamic shroud, mounted as the upper portion of the launch vehicle.



This mission sequence shows graphically how Skylab would be launched and deployed in space.

would conduct experiments and evaluate the habitability of the vehicle, as well as their capability to live and work for long periods in the space environment. At the conclusion of their mission, they would prepare the cluster for unmanned operation, transfer to the command and service module, and return to Earth as they had on earlier Apollo missions.

Some 60 days following the return of the first crew, a second crew of three astronauts would launch to rendezvous and dock with the orbiting vehicle. During this 56-day mission, they would carry out extensive work in solar astronomy and Earth resources observations.

The third manned mission would begin about 30 days following the return of the second crew.

Additional scientific experiments were to be performed, and further data were to be obtained on the crew's adaptability and performance in space.

Objectives of the Program

Skylab was designed to orbit 270 statute miles (235 nautical miles) above the Earth's surface where astronauts would conduct scientific observations in four broad categories.

A carefully planned series of biomedical and behavioral performance experiments was designed to evaluate man's physiological responses and aptitudes in space under zero-gravity conditions and his postmission adaptation to his own Earth environment. Progressively longer missions were



Skylab provided the flight crews and their scientific instruments an excellent view of Earth. Here, Astronauts Pete Conrad and Paul Weitz use the Earth resources optical equipment to study terrain features. The eye patch worn by Conrad is an aid to viewing.

planned to determine the increments by which mission duration could safely be increased.

Additional experiments and work assignments were planned to study man-machine relationships. The purpose of these investigations was to develop and evaluate techniques using man for sensor operations, data selection and evaluation, manual control, maintenance and repair, assembly and setup, and mobility required for various operations.

Continuous operation of Skylab systems over a prolonged period of time was designed to validate techniques for increasing system life, for supporting long periods of operations, and for main-

taining control of the systems throughout the mission.

Finally, experiments were conducted in solar astronomy, Earth resources, science, technology, and applications. Each experiment involved man when his contribution would improve the quality or the quantity of the data.

The Scientific Program

Scientifically, Skylab was a bold beginning. It was the first long-term venture into the exploration of the universe from near-Earth space. It looked inward to Earth, outward to our Sun, and scanned the universe.

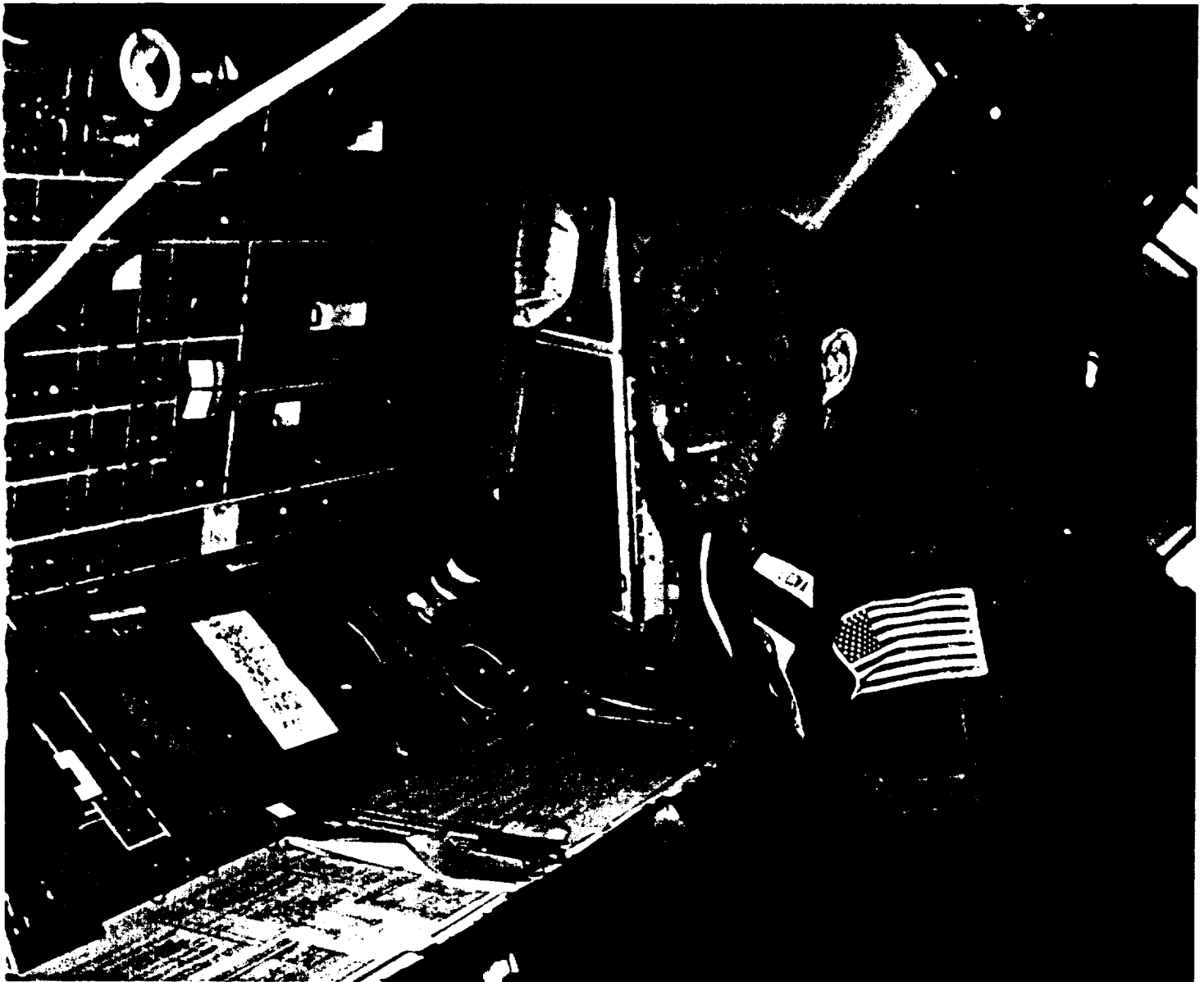
Skylab was equivalent to a small, complex scientific community on Earth. It included equipment similar to that found in Earth-based radio and television stations; physics, biology, and manufacturing laboratories; photographic studios; and well-equipped astronomical observatories.

Flying 50 degrees north and south of the Equator (a range approximately equal to the width of the band between Montreal in Canada and Cape Horn at the southern tip of South America), Skylab completed about 3900 orbits from launch

to the end of the third manned visit, and flew over 75 percent of the Earth's surface, including 80 percent of the developed land and 90 percent of the total population.

The effectiveness of the Skylab crews far exceeded expectations, especially in their ability to perform maintenance and repairs. Each of the three crews completed unscheduled repairs that were critical to the Skylab mission, and each performed with high effectiveness. Because of the astronauts' adapting more readily to the zero-

Seated at the control and display console in the docking adapter, the astronaut manually controlled many important operations, and monitored scientific observations. In this photograph, Jack Lousma of the second crew observes the Sun, watching for the appearance of solar flares. The astronaut's patience was rewarded late in the mission.



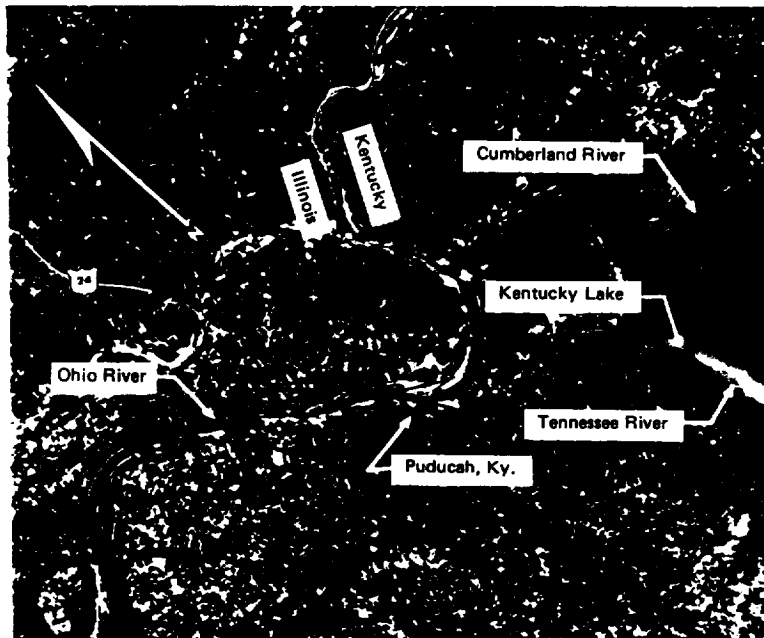


Skylab permitted man to take a long look at the Sun from a vantage point never before enjoyed. (NAVAL RESEARCH LABORATORY)

gravity environment than had been anticipated, and to increase the benefits from the experiments being conducted, the second and third missions were extended to 59 days and 84 days, respectively.

Man was an indispensable element in the Skylab mission. By alertly selecting and photographing "targets of opportunity" on the Sun, evaluating weather conditions on Earth, and taking advantage of unexpected Earth-observation opportunities, crewmen were instrumental in obtaining extremely high-quality solar and terrestrial data. Many experiments conducted inside Skylab could not have been performed as completely by an automated orbiting observatory. All three crews were highly

Skylab permitted a searching study of the planet Earth.



skilled in carrying out scientific experiments and in maintaining Skylab equipment in an operational condition. Their manual adjustment of the space-station controls, precise pointing of experiments, and their reasoning and judgment contributed greatly to the success of the scientific program.

The Sun as Never Seen Before

The Skylab solar experiment program provided much valuable data previously unavailable to the world's solar scientists. Solar images relayed to Earth by television, and photographic films of the Sun returned to Earth by the astronauts, portrayed the Sun as often violent, producing X-ray and ultraviolet emissions that cannot penetrate our atmosphere and, therefore, are never observed from Earth.

Part of the long-term study of Skylab data includes analysis of solar activity as it affects the Earth's weather and communications. In time, Skylab's solar physics experiments may also lead to an understanding of new ways to generate power on Earth.

Further Knowledge of the Universe

From their orbital vantage point, Skylab sensors were able to search the heavens and near Earth to further man's knowledge of the universe. The sensors observed stellar and galactic targets in X-ray, ultraviolet, and visible light. Interplanetary dust was studied by observing reflected light and by measuring micrometeorite impact craters. The passage of Comet Kohoutek was recorded by numerous sensors and vividly described by the crewmen. Energetic particles, like cosmic rays and the protons and electrons trapped in the Earth's Van Allen belts, were recorded by Skylab experiments. The physics of the Earth's upper atmosphere was studied, including observations of atmospheric airglow and ozone layers as well as the northern and southern lights. Measurements were made of the amount of contamination produced by Skylab and its effects on such critical spacecraft components as optical and thermal-control surfaces.

A New Look at Planet Earth

Among the more important benefits of the Skylab program were those resulting from extensive studies conducted of the Earth.

More than 140 scientific teams from the United States and 28 foreign countries united in one of the most exhaustive and most carefully coordinated scientific investigations ever undertaken of our home planet. Skylab's sensors continuously searched the Earth, gathering and recording valuable data. Fixed and hand-held cameras photographed surface features. Other instruments, recording on magnetic tape, measured reflections from plants, soils, and water. Radar made accurate measurements of land and water features, often in remote regions about which only sparse knowledge existed.

Each of the studies conducted had a direct bearing on human life in the rapidly changing Earth environment.

Meanwhile, ground-based crews made similar and simultaneous observations on Earth. Ground and orbital observations were later compared to provide a more accurate assessment of the validity of data from Skylab and future space observatories.

Beyond the Reach of Gravity

The possibility of manufacturing or processing materials under near-zero-gravity conditions has long intrigued the materials engineer. On Earth, gravitational forces lead to thermal convections, sedimentation, buoyancy, segregation, and other effects which may be adverse to the formation of specific materials in which undisturbed lattice structures, homogeneous mixing, or extreme purity are of essence. A series of Skylab experiments was developed to evaluate the advantages of processing materials in space and to test the feasibility of larger scale space manufacturing. Results were highly favorable. Experiment objectives ranged from basic research to actual materials preparation. Scientists expect this program to benefit a multitude of disciplines, including basic materials science, communications, electronics, biological research, and construction in space.

Classroom in Space

From thousands of experiments proposed by high school students for the Skylab student experiment program, 17 were actually performed, including experiments in astronomy, bacteriology, botany, geology, physics, physiology, and zoology. Additionally, the third crew had time to demon-



One of Skylab's interesting features was the Student Experiment Program. Here, Astronaut Owen Garriott televises the performance of the space spider, Arabella, as she adjusts to the weightless environment aboard the space station.

strate familiar scientific principles learned over the centuries. Fluid surface-tension phenomena and free-body inertial effects were demonstrated on television in Skylab's zero-gravity environment in ways that could not be duplicated on Earth. These student experiments and science demonstrations brought the phenomena of space into the classroom and the home. Some are recorded on film for further use.

Man and Space

Mercury, Gemini, and Apollo flights were of sufficient duration to confirm that weightlessness causes biological changes in men, but they left unanswered such important questions as "How long can people live and perform efficiently in the space environment?" and "Can they readjust to Earth?" Skylab answers were conclusive; the adaptability of healthy men in the space environment for long periods substantially exceeded expectations.

The Technical Challenge of Skylab

Technology developed and proved during the Apollo program was employed to hold costs to a minimum. Even so, new techniques were required for many Skylab applications because of the unique character and sophistication of the program. For example, no previous manned program

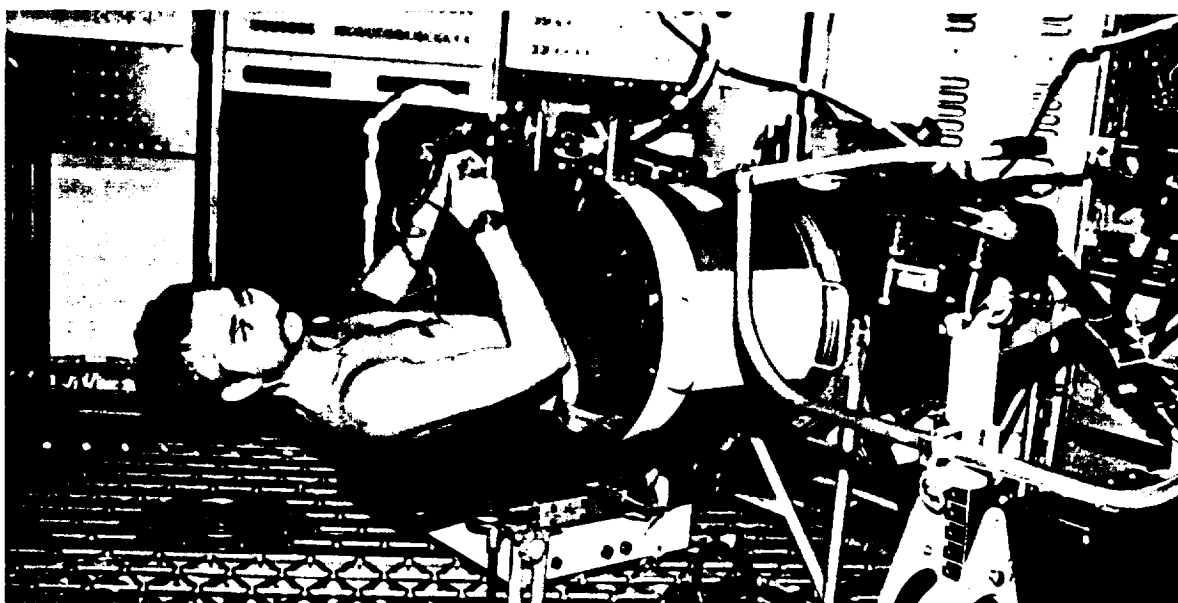
had to operate and provide reliable life support for nearly 9 months. No previous U.S. manned spacecraft had used solar energy to generate all the electrical power needed for operation of its systems. Instrumentation for monitoring the condition of critical equipment required a high degree of accuracy. Pointing control of the solar observatory demanded a precision never before required on manned spacecraft. And closely regulated thermal and environmental control systems were vital to crew comfort and efficiency, experiment operation, and to the proper maintenance of food, medicine, film, and other supplies.

Skylab's lengthy manned periods required high system reliability coupled with a capability to make repairs in space. This was a new requirement for manned spaceflight, demanding a continuing close working relationship between ground specialists and flight crews throughout the mission.

Living in space for long periods of time provided astronauts with interesting and often humorous problems, far different from those faced in our daily routine on Earth. And providing a home and workshop in which the astronauts could live and work comfortably was a design and integration challenge never faced before.

Experience and knowledge gained from earlier space programs, along with years of hard work, resulted in the successful execution of one of the most ambitious scientific and engineering programs

One of the Skylab's principal objectives was the continuing evaluation of man's fitness to live and work in space for long periods. Biomedical and behavioral experiments were conducted on all three manned periods. This space-age gravity tank tested the astronaut's cardiovascular system as it adapted to weightlessness. The tank created a partial vacuum, simulating the pull of gravity. This caused blood to pool in the legs, as on Earth. Sensors measured the ability of the heart to pump blood.



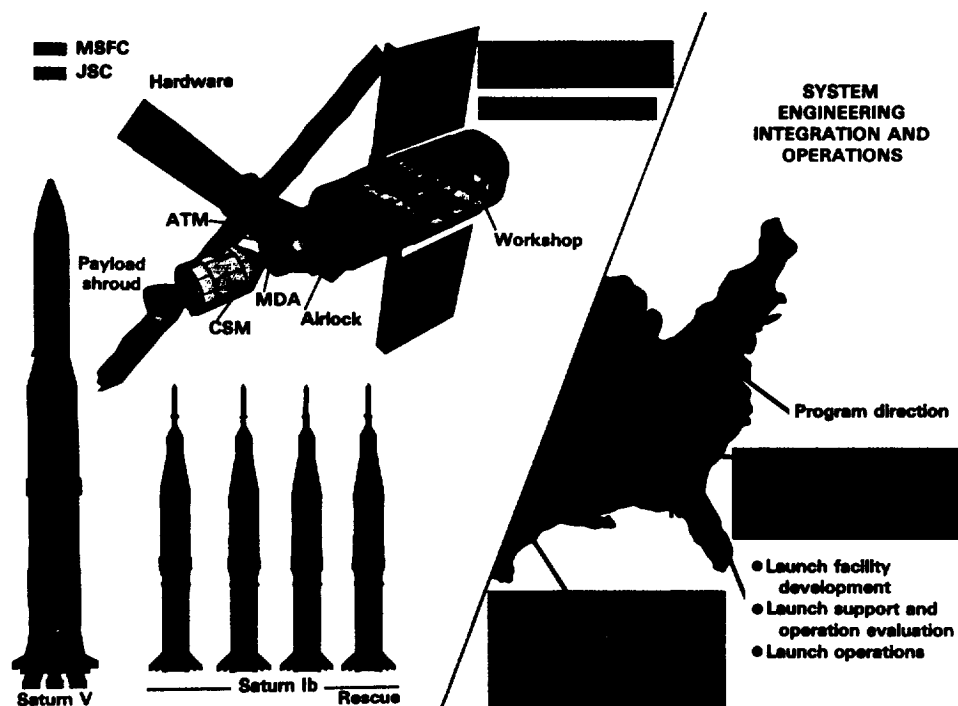
ever undertaken. The full value of the immense amount of knowledge gained during this program will not be known for many years.

The Management Task

Skylab's management scheme was no less innovative than its technical approach. Effective management had to be provided for the combined activities of several NASA centers, over a dozen major contractors, many scientific and educational institutions, other government agencies, and contributions, including experiment hardware, from foreign countries. Management had to insure balanced fiscal and schedule requirements with maximum scientific yield of a multidisciplinary cargo of experiments, while integrating technical requirements for safe, reliable, and efficient operation of the Skylab. This was the Skylab management challenge.

The capabilities of the three Manned Space Flight field centers were employed to meet the challenge. Overall program direction was provided by the Office of Manned Space Flight at NASA

Headquarters in Washington, D.C. The George C. Marshall Space Flight Center (MSFC), Huntsville, Ala., was assigned responsibility for the development of the orbiting space station hardware as well as overall systems engineering and integration of the Skylab to assure the compatibility of the complete mission hardware for each flight. Planning and execution of mission control, flight operations, and adaptation of the Apollo command and service module was the responsibility of the Lyndon B. Johnson Space Center (JSC), Houston, Tex. Planning and execution of launch operations was the responsibility of the John F. Kennedy Space Center (KSC), Kennedy Space Center, Fla. Each center was prominent within its prescribed area in the highly integrated technical and management team formed to implement the Skylab program. Close continuous communication and the implementation of carefully planned and phased technical and management reviews which integrated the expertise of the various participants were an essential ingredient to bringing the program to its successful conclusion.

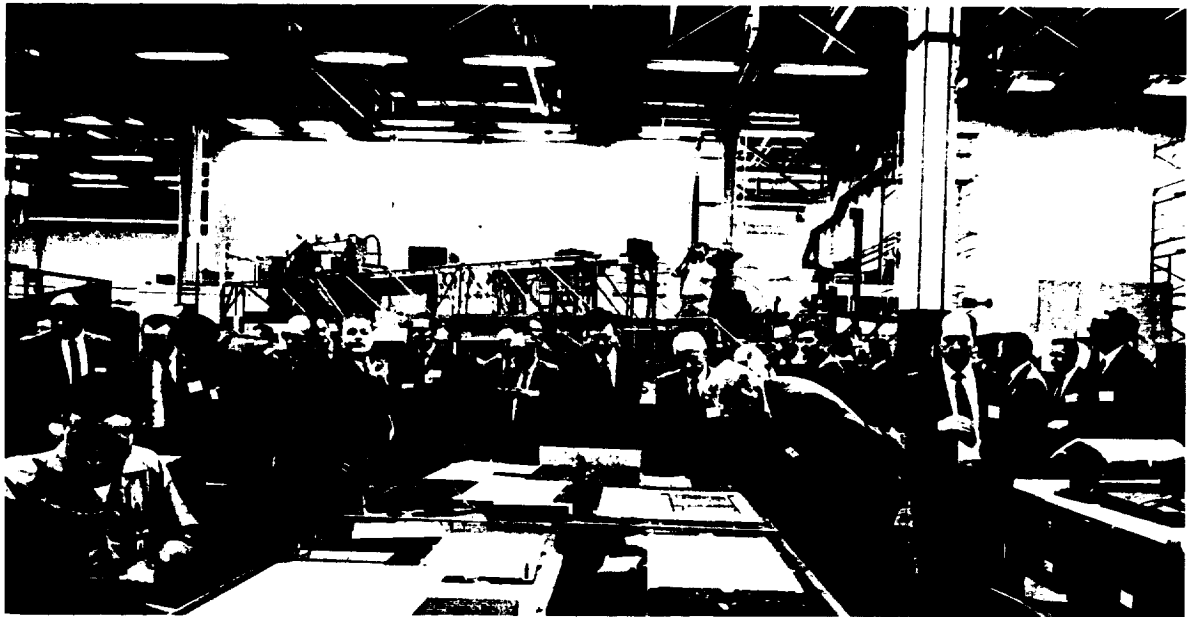


Skylab management responsibilities



Visitors to the neutral buoyancy simulator of the Marshall Space Flight Center, in November 1967, included top-level personnel from NASA Headquarters and several of its field centers. Left to right were Edgar M. Cortright, William E. Stoney, Robert F. Thompson, Kurt H. Debus, Edwin A.

Weaver, Paul H. Schuerer, Charles W. Mathews, William R. Lucas, Wernher von Braun, George Hage, Robert R. Gilruth, Barney E. Evans, Hermann Weidner, George B. Hardy, Julian West, George S. Trimble, Thomas W. Morgan, Maxime A. Faget, and Robert F. Heiser.



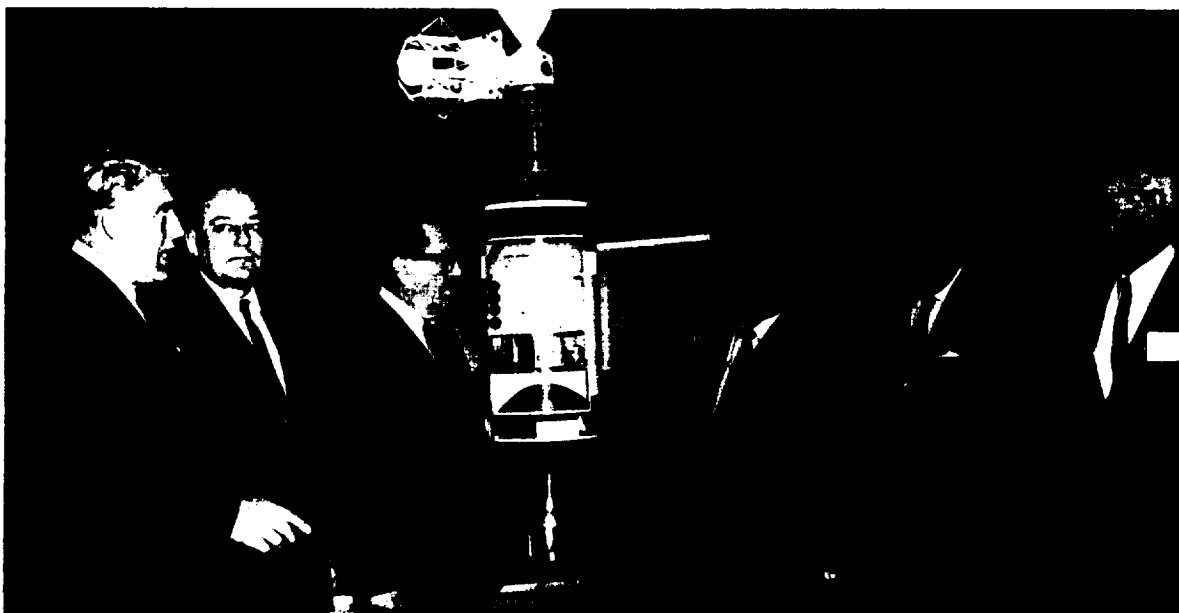
In March 1970, NASA center directors and their staff members visited the St. Louis facility of the McDonnell Douglas Astronautics Co. to review progress on Skylab. Left to right are Thompson, Christopher C. Kraft, Jr., Thomas W. Morgan, Faget, Ludie G. Richard (behind

Faget), unidentified, Walter Burke, Sigurd A. Sjoberg, F. Brooks Moore, Eberhard Rees, Kenneth S. Kleinknecht, Lee B. James, T. J. Lee, Leland F. Belew, Floyd M. Drummond, and Fred A. Speer.



Inspecting launch facilities at the Kennedy Space Center early in the Skylab program are, left to right: von Braun, George E. Mueller, James C. Elms, Rep. Olin E. Teague

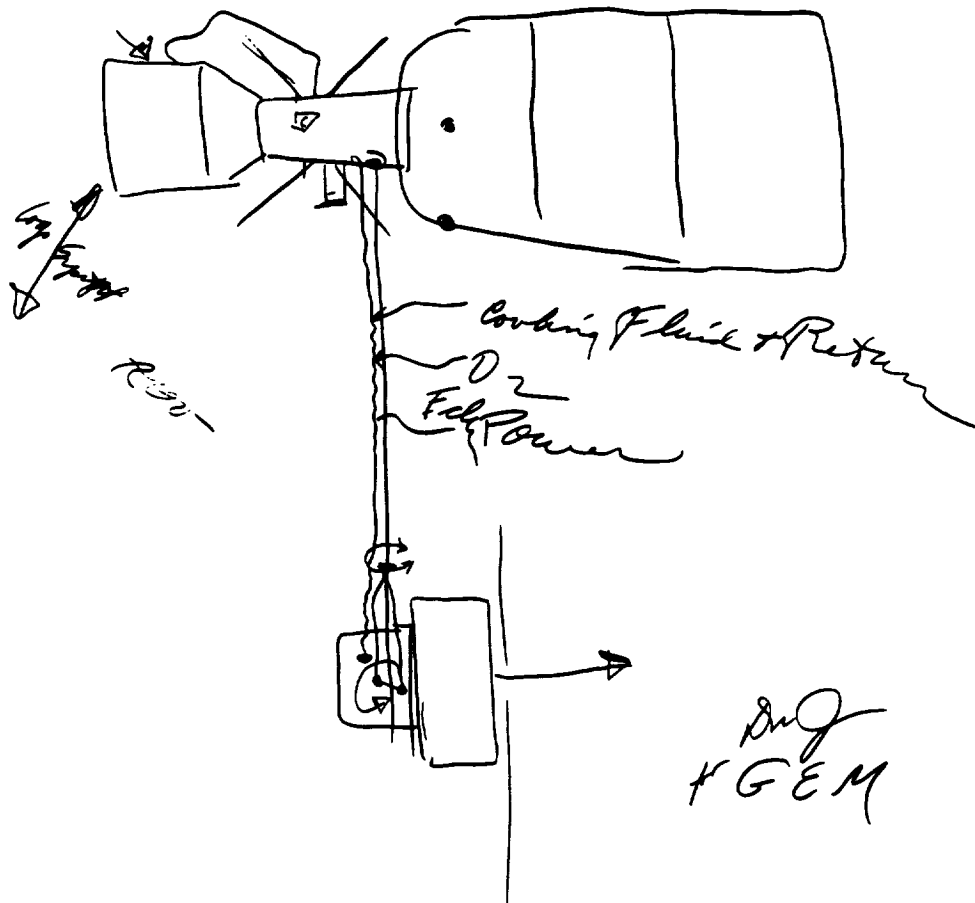
(D-Texas), and Robert C. Seamans, Jr., facing away from camera.



Members of the Congressional Subcommittee on Manned Space Flight received a briefing on the Skylab program during a visit to the Marshall Space Flight Center in March 1969. Left to right: von Braun, Rep. Joe D. Waggoner,

Jr. (D-Louisiana), Rep. Earle Cabell (D-Texas), Representative Teague (D-Texas), Rep. James G. Fulton (R-Pennsylvania), and Ernst Stuhlinger.

To MSFC — 19 Aug 66
 1. Long Duration 1905 CST
 2. Reusability of Expt Mod
 3. Logistic Resupply



Seldom in aerospace history has a major decision been as promptly and concisely recorded as with the sketch shown here. At a meeting at the Marshall Space Flight Center on August 19, 1966, George E. Mueller, NASA Associate Administrator for Manned Space Flight, used felt pen and poster paper to pin down the final conceptual layout for the budding space station's major elements. Gen. Davy Jones, first program director, added his initials and those of Dr. Mueller in the lower right corner.

2

Our First Space Station

On the afternoon of May 14, 1973, Skylab was ready to begin its mission. Saturn V launch vehicles had roared off Launch Complex 39 at Kennedy Space Center many times before, sending astronauts on journeys to the Moon. On this warm spring day, a complex cluster of scientific hardware, which would become an orbiting home and laboratory in space, was to be the passenger.

Skylab's story began more than a full decade earlier. The Apollo command and service module was a versatile spacecraft, capable of carrying sophisticated scientific equipment into orbit, but its capability for manned scientific operations was extremely limited. To perform the scientific tasks envisioned for Skylab, skilled astronauts would have to live and work in a well-equipped scientific laboratory for long periods of time, and be essentially independent of the need for frequent resupply. This requirement demanded that electrical power be generated by systems aboard the space station and that highly reliable communications, data collection, instrumentation, and control systems be provided. A rocket stage, its tanks emptied of propellant, and modified inside for living and working quarters, seemed a logical means of providing such a roomy space station. Skylab evolved slowly from an initial concept in which the tank was to be converted into a habitable volume in orbit; in the final concept, the stage was launched dry ready for occupancy by the flight crews once it reached orbit. Power, communication, instrumentation, and control systems evolved



An intermediate concept envisioned a cluster which included a lunar module, the solar observatory with its windmill-like solar arrays, and a command and service module.



In a "wet workshop" concept, the Skylab cluster consisted of a lunar module with the solar observatory mounted above it, a command and service module, a docking adapter, and a Saturn upper stage, emptied of its propellants in achieving orbit. This spent stage would be outfitted in orbit for occupancy.

as the workshop design matured. Provisions were made for crew health and comfort. Equipment for making precise scientific measurements and conducting experiments was developed. The result was a space laboratory of unequaled sophistication, ready to be propelled into orbit by the giant Saturn.

Skylab To Provide Answers to Many Questions

The Gemini 7 crew of Frank Borman and James Lovell had remained aloft for nearly 2 weeks and the Russian cosmonauts of Soyuz 9 had orbited Earth for 18 days. But bioscientists remained concerned about man's ability to adapt readily to the length of mission planned for Skylab, whose crews were to spend as long as 8 weeks in space. The long-range physiological and psychological effects of weightlessness on man were still not fully understood. Nor was it known whether even the highly trained and superbly conditioned astronauts could perform the varied tasks expected of them for such extended periods of time in space.

Other scientists wanted to use zero-gravity conditions for materials research, even with a view to

eventual commercial applications, such as precision in manufacturing.

The ability to make more exact observations of both Earth and the solar system than ever before possible spurred additional interest in Skylab and imposed new requirements on the design. Solar scientists had long dreamed of observing the Sun without interference from the Earth's atmosphere. The shell of atmospheric gases which nourishes and protects the Earth also severely limits man's ability to view celestial objects, even with the finest and largest telescopes made. An observatory orbiting above the Earth's atmosphere and equipped with fine resolution instruments would be an extremely valuable tool for solar scientists.

Other scientists, desiring to know more about the planet Earth, saw in Skylab a platform from which photographs and visual observations could be made on a vastly larger scale than ever before. Others of the scientific community saw in this orbiting laboratory an ideal environment for conducting unique experiments in space physics and life sciences.

The development of an orbiting laboratory with so varied a capability was a technical challenge

without precedent. As envisioned, Skylab was to be self-sufficient, with direct communication with ground crews. This required a highly complex spaceflight tracking and data network for the transmission of instructions, for the recording of data, and for voice and TV communication.

Living in space in a controlled environment dictated the further development of a comprehensive and extremely reliable life-support system. And long-duration spaceflight required that provisions be made for crew recreation and relaxation, exercise, and for moving around easily within the space station.

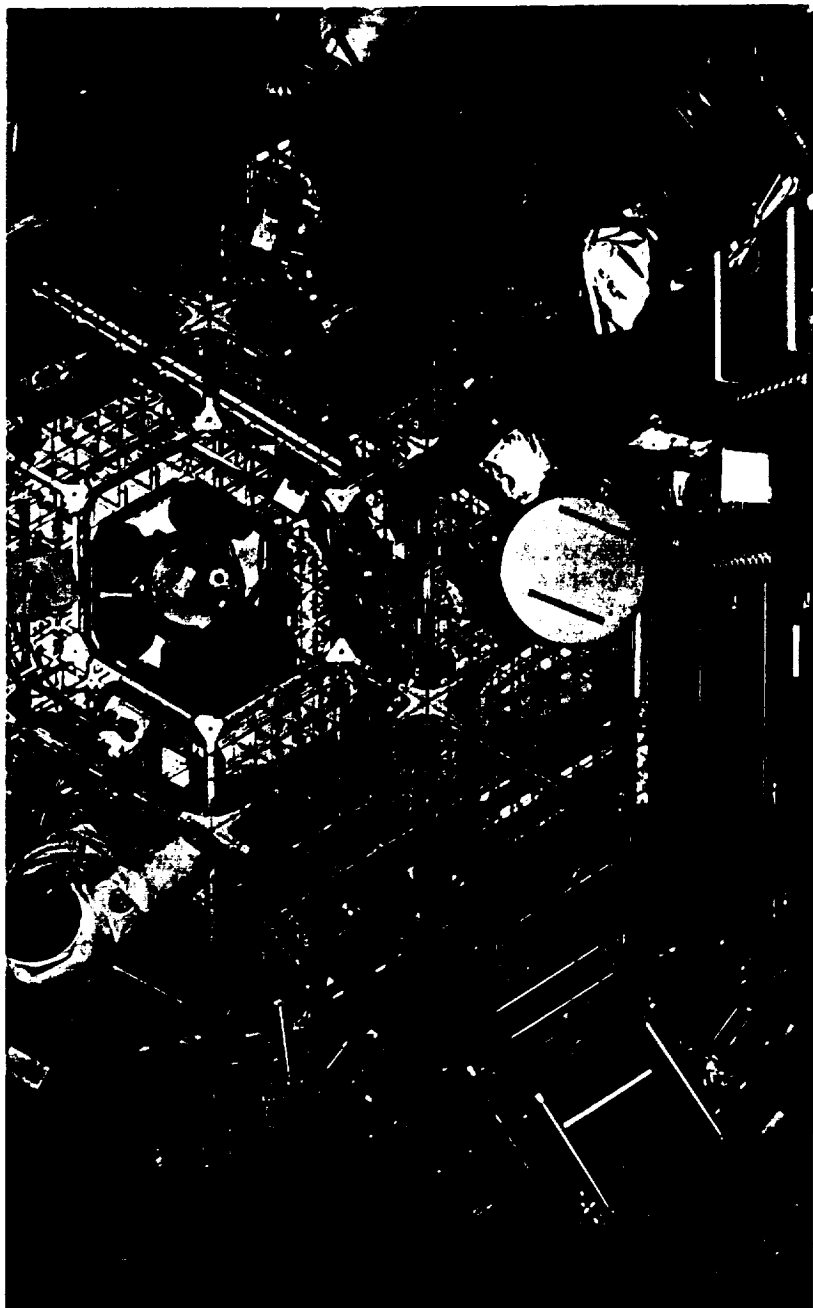
Many factors influenced the final design configuration of Skylab. However, one of the most important was an economic necessity to use components and equipment, where possible, that had been developed for other programs.

When launched, Skylab contained all the elements needed to sustain the crews and their planned operations. Breathing gases, food, and water were stored on board, along with medicine and other expendable supplies. Systems within the space station provided for the collection and disposal of human waste and an atmosphere controlled as to temperature, pressure, and humidity so that the crewmen could live and work in comfort. Solar arrays mounted on the workshop and the solar observatory produced electrical power by the direct conversion of solar energy. Two precise control systems permitted the astronauts to orient the workshop to collect experimental data and to position Skylab so that its solar arrays faced the Sun.

Design Problems Were Many

Transforming an empty rocket tank into a home and laboratory imposed some tough problems in engineering. Their solution often required that designers break with earthly tradition.

How does one equip living and working quarters where up and down have no real meaning? What controls, displays, instruments, and sensors are needed? How will the occupants keep their home free of floating debris? Where will they stand or sit while working? How will they bathe, shave, brush their teeth, or use the toilet? How will they get from one place to another quickly and safely when they cannot walk? These were typical questions which had to be answered before the interior of Skylab could be designed.



Skylab resembled a home and workshop only in its functional capability. Floors and ceilings were open grids; up and down became relative; and voices carried only a few feet in the thin atmosphere. But the flight crews quickly adjusted and carried out their tasks skillfully.

The manned spaceflight program conducted by NASA has been evolutionary. Mercury paved the way for Gemini. Gemini provided information essential to Apollo. And lessons learned in Apollo were applied to Skylab.

Answers came, too, from habitability studies. Exhaustive studies were conducted at the NASA spaceflight centers and at a number of the aerospace contractor facilities. Data came from Navy studies of long-duration submarine voyages. Information useful in designing compact systems came from designers of railway passenger cars, marine designers, and others. Out of such studies emerged a wealth of information about man under stress in confined and isolated environments.

Astronauts and support crews took part in numerous studies which simulated conditions that were nearly identical to those to be encountered in space.

An important habitability study was the medical experiments altitude test conducted at the Johnson Space Center. This test was a simulation of a 56-day mission, which included all significant features of the Skylab environment with the exception of weightlessness. The atmosphere was identical to that of Skylab, a 74-percent oxygen and 26-percent nitrogen breathing mixture at 5 pounds per square inch (versus 14.7 pounds per square inch on Earth). Crew quarters were simulated; crew activities (principally those associated with medical experiments) were identical to those to be carried out in Skylab; three astronauts performed tasks in accordance with a schedule of events prepared for the actual mission; and support personnel manned a mission control room. Many problems were identified and corrected. Medical data were collected before, during, and after the test to evaluate the health of the flight crew.

At the Marshall Space Flight Center, astronauts and engineers spent hundreds of hours in a neutral buoyancy zero-gravity simulator rehearsing procedures to be used during the Skylab mission, developing techniques, and detecting and correcting potential problems.

This simulator is a huge water tank, into which full-scale Skylab hardware was placed. Astronauts and other subjects were then weighted and their equipment was made neutrally buoyant by the addition of light foam pads. In this way the effective gravity conditions under which they

worked were nearly identical to those they would later encounter during Skylab flights.

Later, this simulator was to play a vital role in supporting "real time" development of equipment, techniques, and procedures for emergency repairs in space.

Valuable data also came from other sources. For example, when the noted Swiss oceanologist, Jacques Piccard, assembled his six-man crew for the summer 1969 voyage of the submarine *Ben Franklin*, a NASA engineer was aboard as a member of the crew to obtain data on human reactions in a confined environment. Later, a number of the NASA engineers participated in the *Tektite II* underwater research program.

Even with this exhaustive preparation, many new problems arose. That they were solved satisfactorily is a tribute to the ingenuity and dedication of those men and women who labored so long to make the program a success.

The needs of the Skylab home and laboratory were considerably different from those for homes and laboratories on Earth, where designers must



Extensive testing and many hours of practice in simulators such as the neutral buoyancy tank helped prepare the Skylab crewmen for spacesuited performance in the weightless environment. This huge water tank simulated the weightless environment which the astronauts would encounter in space.



Much valuable data about behavior and the problems associated with living in close quarters came from underwater studies. NASA engineers took part both in the *Ben Franklin* (pictured above) voyage in 1969, and later in the *Tektite II* underwater research program.

consider a constant force of gravity. Earth structures are designed to withstand the stresses caused by the weight of the structure, permanent and transient equipment, and the loads which occur due to people who occupy or pass into and out of the structure. Dynamic stress occurs primarily from wind loads or other natural phenomena such as earthquakes.

Design of Skylab also considered gravity, but not as a constant force. The compressive forces exerted on Skylab during its mission ranged from zero to about four and one-half times the force of gravity on Earth. Thus, loads of nearly 500 tons occurred where the space station joined the Saturn

V second stage during the period of maximum acceleration, when engine thrust was accelerating Skylab into orbit. Wind loads were compounded by aerodynamic forces as the speed of Skylab increased rapidly while in the Earth's atmosphere. Aerodynamic loads caused both compressive and bending forces. Additional bending forces, even more severe than compressive forces, resulted from steering movements of the rocket engines which kept Skylab on course as it ascended.

Docking the command and service module to the space station caused shock forces similar to the effects of earthquakes on Earth-based structures.

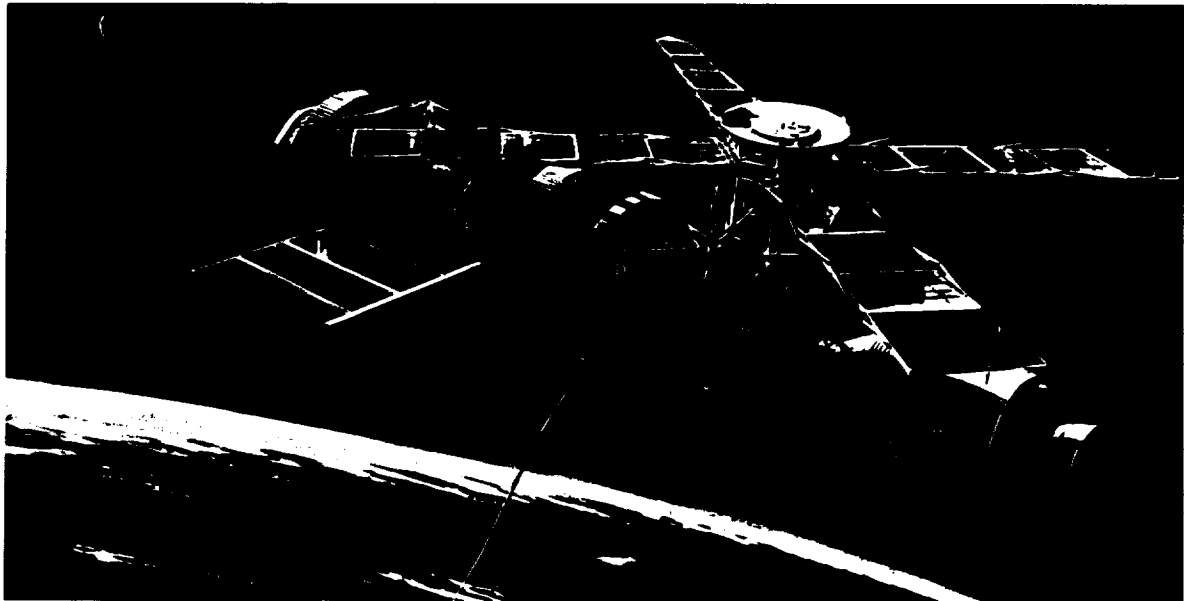
Structural designers assured that the total Sky-

lab assembly could withstand all reasonable loads encountered during handling, launch and ascent, solar observatory deployment, attitude changes, and docking operations with the command and service modules, and also could maintain a pressure-tight enclosure suitable for habitation.

It was impractical to make the habitable area completely leakproof, because of the mating surfaces and many penetrations for electrical cables, tubing, windows, and hatches. But leakage was

held to a minimum to avoid carrying an excessive amount of gas to replenish the habitable atmosphere.

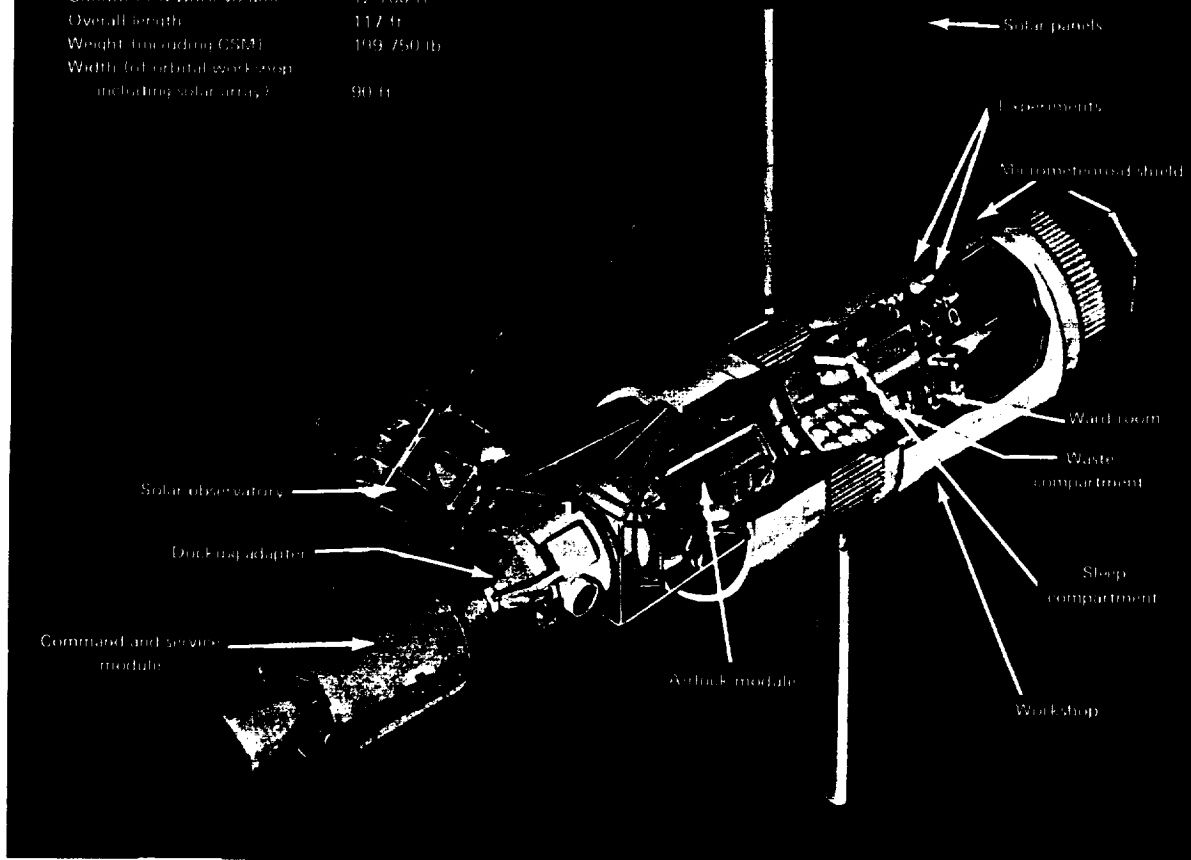
Each habitable structure was pressure tested prior to launch. The workshop was pressurized during launch to provide rigidity; controlled venting during ascent maintained the required strength without the differential pressure increase that would have resulted otherwise. The airlock and docking adapter were launched with sea-level pres-



	A	B	C	D	E
Module	Command and service module	Docking adapter	Solar observatory	Airlock	Workshop
Manufacturer	Rockwell International	Martin Marietta	MSFC	MDAC-Eastern	MDAC-Western
Module name (development)	Command and service module	Multiple docking adapter	Apollo Telescope Mount	Airlock module/ fixed airlock shroud	Orbital workshop
Function	Crew ascent and descent	Docking interface Controls and displays Earth observation Stowage	Solar observation Power source Attitude control	Power control and distribution Environmental control Data center Extravehicular activity hatch Caution and warning	Primary living and working area Laboratory Power source Stowage
Length	10.45 m (34.3 ft)	5.27 m (17.3 ft)	4.05 m (13.3 ft)	5.36 m (17.6 ft)	14.66 m (48.1 ft)
Diameter	3.96 m (13.0 ft)	3.04 m (10.0 ft)	3.35 m (11.0 ft)	3.04/1.67/6.70 m (10.0/5.5/22.0 ft)	6.70 m (22.0 ft)
Habitable working volume	5.95 m ³ (210 ft ³)	32.28 m ³ (1140 ft ³)		17.66 m ³ (624 ft ³)	295.23 m ³ (10 426 ft ³)

General characteristics

Conditioned work volume	12,700 ft ³
Overall length	117 ft
Weight (including CSM)	199,750 lb
Width (for orbital work area including solar array)	90 ft



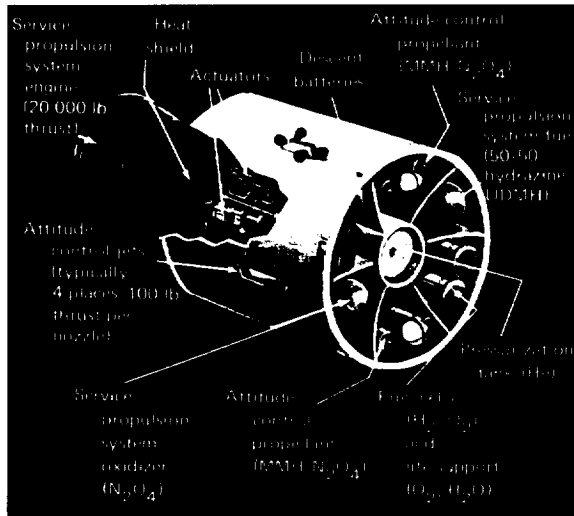
General characteristics of the Skylab cluster

sure internally and this pressure was allowed to decay through valves as Skylab ascended, since pressurization was not required to strengthen these modules.

Each of the five major assemblies making up the Skylab cluster played an important role in the mission. In orbit, the cluster resembled a series of essentially cylindrically shaped components joined together with solar wings extending outward from the sides of the largest cylinder. Extending outward perpendicularly from the center cylinder was another cylindrical device on top of which was mounted four windmill-like rectangular solar wings.

The command and service module, the crew ascent and descent vehicle, consisted of the manned command module and the unmanned service module. The command module was conical in shape, about 13 feet in diameter and 12 feet high; it contained a crew compartment approximately 7 feet wide, 6 feet high, and 4 feet from front to back. A docking tunnel extended from the crew compartment to the nose of the vehicle to allow the crew to enter the docking adapter through its axial port.

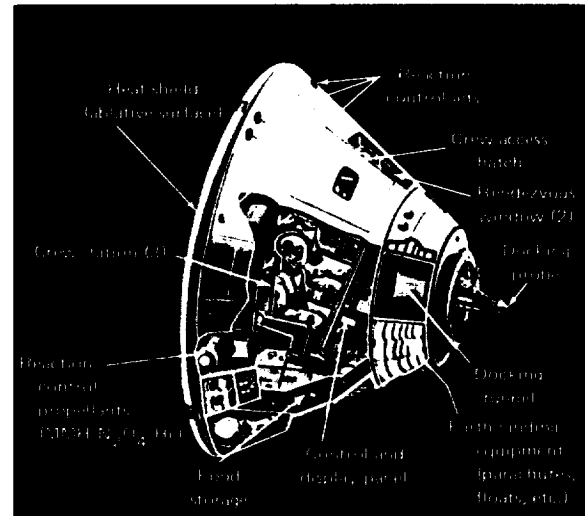
Within the command module were its attitude control and guidance systems, batteries, control and display panels for the command and service



Service module

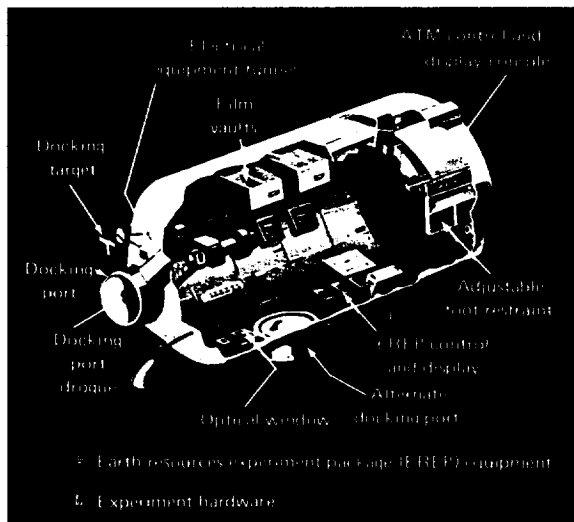
module systems, the couches that supported the crew during launch, ascent, reentry, and landing, stowage compartments for consumables, and stowage provisions for equipment to be taken to or returned from Skylab.

The crew compartment was protected by a heat shield coated with material that burned away during reentry and dissipated the intense frictional heat.

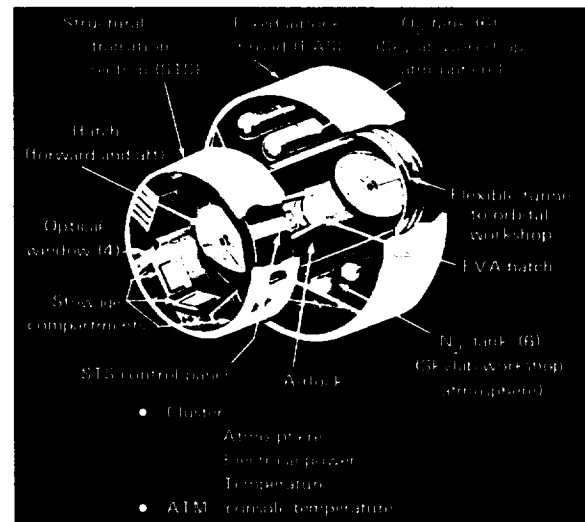


Command module

The service module was about 13 feet in diameter and about 25 feet long. This unmanned vehicle contained the equipment and supplies that did not require direct crew accessibility during flight. These included the main command and service module propulsion system with its 20 000-pound thrust engine, a smaller reaction control system for maneuvering the spacecraft,



Docking adapter



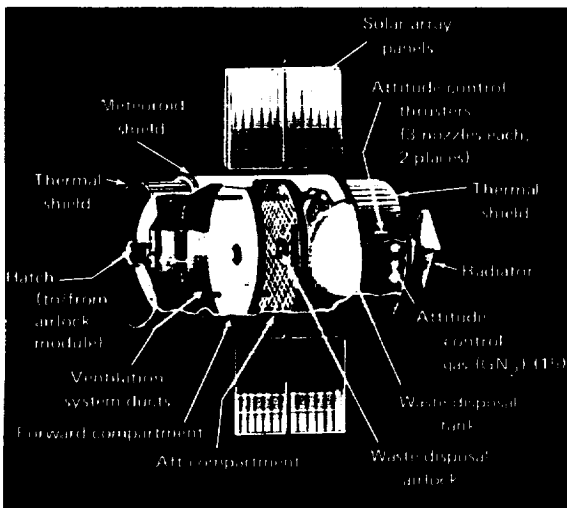
Airlock

hydrogen and oxygen fuel cells for generation of electrical power, and radiators for cooling. The service module remained attached to the command module until near the end of the mission. Separation occurred just before atmospheric reentry, and the service module burned in the atmosphere.

The Skylab docking adapter, 17 feet long and 10 feet in diameter, was as large as many earlier spacecraft. It was the control center for solar, Earth observations, and metals and materials processing experiments. Many of the experiments and items of other equipment were stowed in the adapter.

Two docking ports were provided in the adapter. The primary port was axial and was located at the forward end. The alternate port, located on the side of the module, could have been used if a rescue became necessary. Cameras and Earth resources sensors were located adjacent to the alternate docking port; some were positioned at a window in the wall, others actually protruded through the wall. Vaults, for storage of film for the solar experiments, protected the film from the radiation experienced at orbital altitude.

The control and display console for the solar observatory was located at the rear of the docking adapter, where solar activities could be monitored by the astronauts on two television screens. This console also contained the instruments and controls for the attitude-control system and for the solar observatory electrical power system.



Workshop

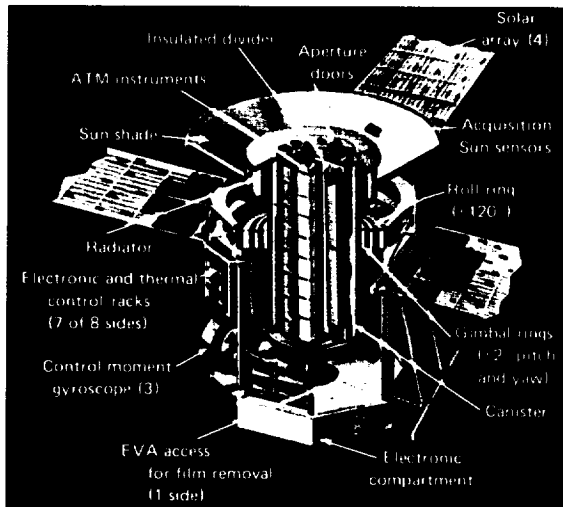
The aft end of the docking adapter mated to the airlock module, which served as the environmental, electrical, and communications control center. It also contained the port through which the astronauts exited to perform extravehicular activity. The airlock contained a tunnel section through which Skylab crewmen could move between the workshop and the forward end of the airlock. It was encircled for part of its length at its aft end by the fixed airlock shroud, which had the same diameter as the workshop (22 feet) and was attached to the workshop's forward end. High-pressure containers for oxygen and nitrogen, which provided Skylab's atmosphere, were mounted in the annular space between the outside of the tunnel and the inside of the shroud. The forward end of the fixed airlock shroud was the base on which the tubular structure supporting the solar observatory was mounted.

Two hatches were provided to close off a section of the tunnel. A third hatch was located in the outer wall between these two hatches and was the opening through which the crew passed to perform tasks in space. A hatch was also located in the forward end of the workshop. Closing either the two airlock tunnel hatches or the forward airlock tunnel hatch and the workshop hatch prior to opening the hatch in the tunnel outer wall retained the atmosphere within the rest of the cluster.

The workshop was divided into two major compartments. The lower level provided crew accommodations for sleeping, food preparation and consumption, hygiene, waste processing and disposal, and performance of certain experiments. The upper level consisted of a large work area and housed water storage tanks, food freezers, storage vaults for film, the scientific airlocks, the mobility and stability experiment equipment, and equipment for other experiments. The compartment below the crew quarters was a container for liquid and solid waste and trash accumulated throughout the mission.

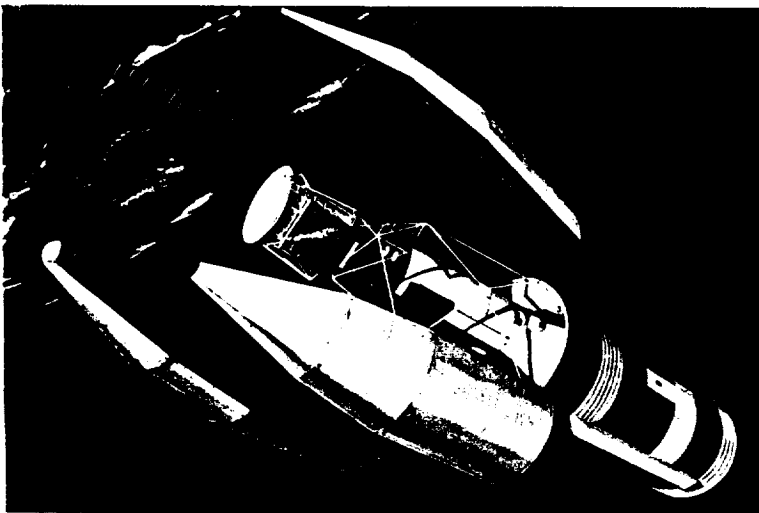
A solar array, consisting of two wings covered on one side with solar cells, was mounted outside the workshop to generate electrical power to augment the power generated by another solar array mounted on the solar observatory. Thrusters were provided at one end of the workshop for short-term control of the attitude of the space station.

The large size of the workshop made a reliable



Solar observatory

intercom system a necessity. Crewmen could talk to each other or to ground crews from any one of 12 locations. (Unaided voice communication between astronauts was difficult because of poor transmissibility caused by low atmospheric pressure in Skylab.)



Once in orbit, the protective aerodynamic shroud was jettisoned. For several orbits thereafter, the panels of the shroud trailed Skylab as it orbited.

The solar observatory was mounted on a truss structure extending outward from the forward end of the workshop and surrounding the airlock and docking adapter. Solar observatory experiments and related support equipment as well as items of equipment to support the basic laboratory were mounted on this structure.

The major element of the solar observatory was a cylindrical canister containing the experiments. It included a spar and two canister halves. The spar structure was insulated and had the experiments and rate gyroscopes installed on low conductance mounts. The canister halves were isolated from the spar and provided thermal and mechanical protection. Additional equipment carried in the solar observatory assembly included the sensors, momentum wheels, and computers for attitude control of the workshop.

Several additional assemblies played a major role in the Skylab program. These were the airlock shroud, the payload shroud, and the deployment assembly.

The payload shroud was both an environmental shield and an aerodynamic fairing. Attached to the forward end of the fixed airlock shroud, it protected the airlock, the docking adapter, and the solar observatory before and during launch. It also provided structural support for the solar observatory in the launch configuration. Once Skylab reached orbit, the payload shroud was jettisoned.

During the early part of the Skylab mission, observers on the ground often saw Skylab traveling across the sky followed by several bright objects. These were the jettisoned panels of the payload shroud and the second stage of the Saturn V.

The deployment assembly provided in-orbit structural support between the solar observatory and the fixed airlock shroud and deployed the solar observatory when Skylab reached orbit. It also served as a mounting fixture for some experiments, acquisition lights, VHF-ranging antenna and wire routing from the solar observatory to the workshop. It consisted of tubular truss members, a release operated by an explosive bolt system, a rotation system for moving the observatory into its orbital position, and latches to lock it there.

Skylab's Systems

Skylab's systems were designed to minimize the need for expendable supplies. Power, generated by the conversion of solar energy, was stored in

batteries. Spacecraft attitude was controlled by three large gyroscopes. Cooling was accomplished principally by radiating heat to space. The atmosphere was scrubbed of carbon dioxide by a reusable molecular sieve. Thus, except for the supplies specifically required by the astronauts, such as air, food, and water, Skylab's systems sustained operation over a long period with minimum replacement or maintenance.

Skylab's major systems controlled its attitude, generated and distributed electrical power, controlled its environment and temperature, and furnished communications capabilities.

The position of Skylab in space was controlled by an attitude and pointing control system. This function included rotating to predetermined orientations, holding the required orientation for as long as necessary, and providing precise pointing for the solar experiments.

To execute a change, the system recorded the desired attitude, checked the existing attitude and compared it with that desired, initiated the change maneuver, and terminated the maneuver once the desired attitude was reached.

A rate gyroscope system measured attitude rates which were used to derive the space station attitude. Reference attitude information was provided by a Sun sensor that indicated whether it was pointed at the Sun or not, and a star tracker that sensed the location of predetermined stars (Canopus and Achernar in the southern hemisphere, for example) and indicated their direction relative to Skylab's three axes.

The prime mechanisms for executing maneuvers were the control-moment gyroscopes, which were momentum storage devices. Three large gyroscope wheels (rotors) were mounted in gimbals with their axes mutually perpendicular like the edges of a box at a corner. To maneuver the Skylab, the astronaut entered the desired attitude into the digital computer, which compared the desired attitude with the existing attitude (derived from rate gyroscope data). If rotation was required, the axis of one or more of the control-moment gyroscopes was rotated to a new position by computer command; this caused a reactive force and rotation of the space station in the desired direction. When the desired attitude was achieved, momentum was transferred back to the gyroscopes, causing vehicle rotation to stop. The gyroscopes were then in approximately their original inertial orientation.

A second maneuvering system, the thruster attitude control system, consisted of six nitrogen gas expulsion nozzles mounted at the aft end of the workshop. By thrusting in the required direction, they rotated the vehicle to the desired position.

During orbital operation of Skylab, all the electrical power used was generated by two solar arrays. One array deployed in the form of two "wings," one on each side of the workshop; the other array consisted of four "wings" deployed from the solar observatory.

The Skylab orbit, however, took the vehicle out of sunlight for about one-third of the time. In order that the Skylab systems could operate during the periods of orbital darkness, batteries were charged from the solar arrays during sunlight periods.

An environmental and thermal control system was needed to provide a breathable atmosphere inside Skylab and to maintain the temperature of crew and equipment within tolerable limits. Before each crew arrived, Skylab was pressurized. Air purification and humidity control were achieved by passing the gases through carbon dioxide and odor removal filters and through water condensers.

Skylab was subjected both to intense heat and intense cold. Passive thermal control, in the form of insulation and thermal coatings on the workshop, airlock, and docking adapter, helped attenuate the effect of these thermal extremes on internal workshop temperatures.

To control temperature and humidity within Skylab, an active thermal control system was provided. This system provided heat through a combination of air-duct heaters and wall heaters. The heaters prevented condensation from forming and damaging instruments and equipment. Humidity control was achieved by passing air through heat exchangers that condensed the moisture. Cooling was provided by these heat exchangers and others which cooled air passing through them but did not remove moisture.

Heat-producing equipment was cooled by refrigerator-like cold plates. The temperature of these plates was maintained by a liquid coolant pumped to heat exchangers. The excess heat collected was dumped to space through radiators.

Thermal control of the solar observatory was provided by a system of passive control measures, radiant heaters, cold plates, and radiators similar to



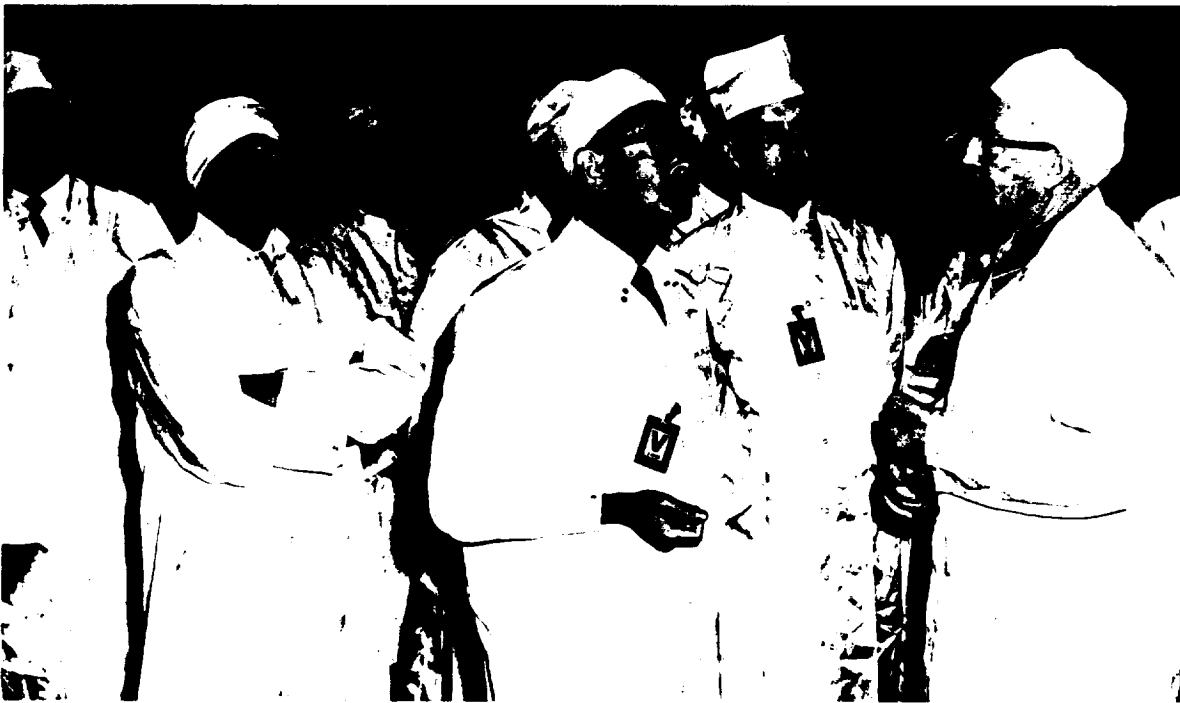
Assembled for a management meeting in the facilities of the McDonnell Douglas Astronautics Co., St. Louis, in April 1971, were, left to right: Eberhard Rees, Leland F. Belew, Kenneth S. Kleinknecht, William C. Schneider, and Kurt H. Debus.



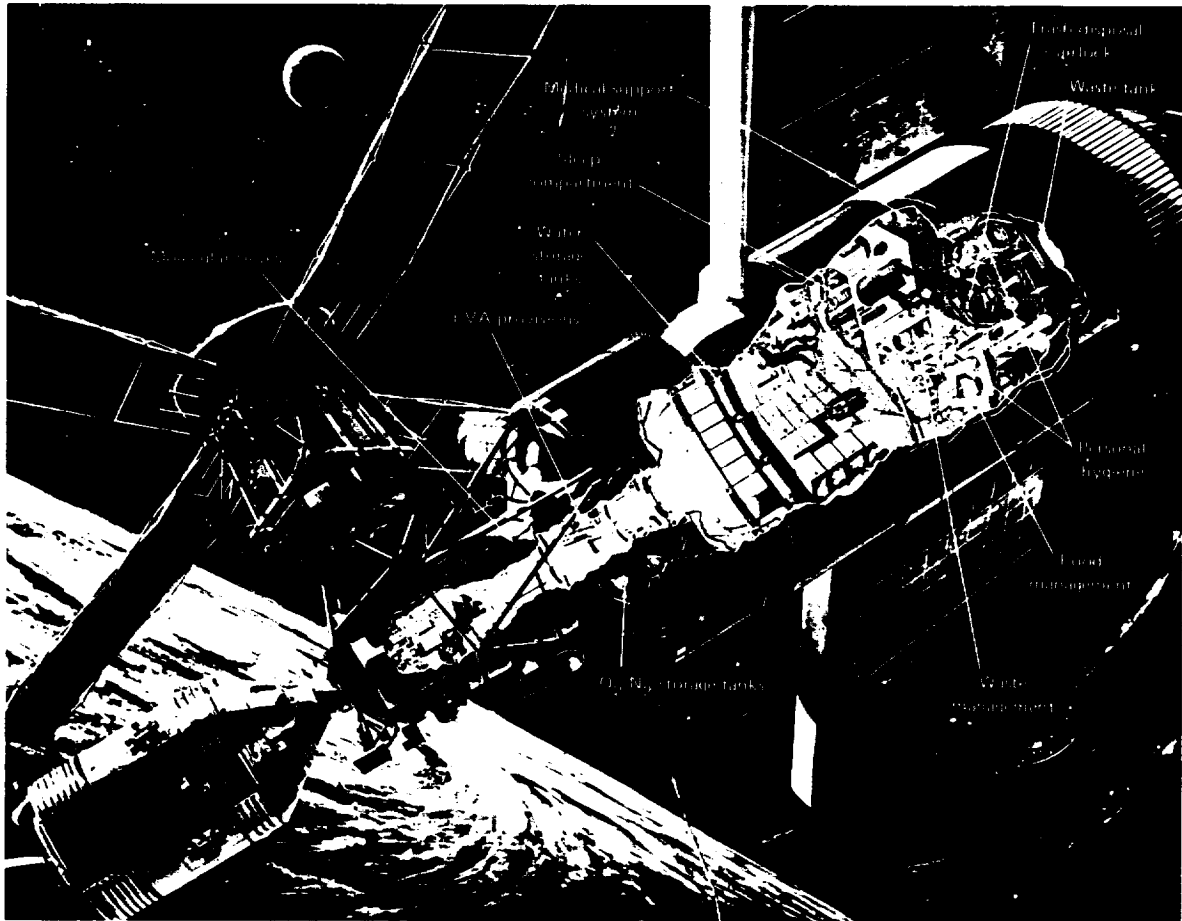
On hand for the "rollout" ceremonies for the orbital workshop at Huntington Beach, Calif., in September 1972, were, left to right: Willis H. Shapley, Casper W. Weinberger, James C. Fletcher, Rees, Walter Burke, and Dale D. Myers.



Inspecting the airlock trainer at St. Louis, in April 1970, were, left to right, Belew, James S. McDonnell, and George Radebush.



Skylab officials visiting the facilities of the McDonnell Douglas Astronautics Co., in St. Louis, January 1972, donned special garments to enter clean rooms. Left to right: Fred J. Sanders, Rees, William K. Simmons, Jr., Myers, Belew, and E. T. Kisselberg.



Life-support system

those used in the crew compartment system. A Sun shield shaded much of the solar observatory equipment from direct sunlight.

Spacecraft-to-ground communication was effected through the command module radio for talk between the Skylab crews and the mission controllers at Houston. In addition to voice communication, radios in Skylab transmitted scientific data to Earth and received and implemented commands sent from the Mission Control Center.

A TV system routed television signals from five cameras on the solar telescopes to the control and display panel. A portable color television camera provided views of internal activity and astronaut activity outside Skylab.

Measurement systems with sensors acquired and processed information on the active Skylab systems and experiments, including air pressure, temperatures, electrical power system measurements, experiment data, and crew biomedical information from sensors worn by the crewmembers. The instrumentation system processed all the measurement signals into a form suitable for transmission and transmitted them to Earth or recorded them on tape depending on the availability of ground communications contacts.

The Orbital Workshop

Skylab's three manned periods totaled 171 days in space, dictating a need to provide the crews with

comfortable living quarters and a healthy and safe living and working environment.

Although primary attention was given to functional layout of equipment and compartments for effective operations within the workshop, the design also carefully considered the astronauts' surroundings. Colors were selected for a pleasing appearance. Lighting was arranged to provide best visibility. Controls and displays were located for ease in operating the equipment.

Skylab's mission required that large quantities of supplies be stored. In all, more than 19 500 items were stored and cataloged in a number of preselected locations.

The air in Skylab was much like that on Earth, except that it was free of pollutants and the usual "trace elements" such as helium and argon. Oxygen and nitrogen were stored separately and supplied automatically to keep the breathing atmosphere a mixture of about 3 parts oxygen and 1 part nitrogen. This oxygen level was necessary to maintain the sea-level-equivalent oxygen pressure. (On Earth, because of the higher atmospheric pressure, the mixture of these gases is just the reverse—about three-fourths nitrogen and one-fourth oxygen.) Losses due to leakage or crew consumption of oxygen were automatically replenished. As long as the workshop remained manned, the pressure inside was maintained at 5 pounds per square inch.

Maintaining comfortable temperatures inside the orbiting workshop depended not only on the effectiveness of its environmental control systems but also upon the ability to shade the exterior of the workshop from the Sun's direct rays.

Skylab's design included a shield to shade the workshop and to protect the workshop from possible structural damage from the micrometeoroids which continuously travel through space at very great speeds. This thin aluminum structure was made of 16 long, rectangular panels hinged together. During launch, panels were held tightly against the outer skin of the workshop by a number of tension straps. Once Skylab was outside the Earth's atmosphere, torsion bars would rotate to separate the shield from the workshop and deploy it so that it was separated from the workshop by about 5 inches.

Since this shield, in effect, became the outside surface of the workshop, it was very important to the control of temperature.

New Requirements for Living in Space

Crew quarters were on the lower level of the workshop. This level housed the kitchen and dining room, bedrooms, an experiment work area, and the toilet.

In the wardroom or kitchen and dining room the crewmen chose their menus from a variety of frozen and dehydrated foods. Various kinds of meat, vegetables, cereals, and desserts were readily available. Foods that would stick to a spoon or fork were eaten with the usual table utensils, which were held in place on the table by magnets when not in use. Liquids were served in squeezable plastic containers.

All three crewmen could eat at the same time at a dining-room table designed so that each crewman could heat his food individually in a tray. This table also included the water chiller and the water heater.

The absence of gravity made it possible to eliminate things that we on Earth take for granted. For example, beds were not necessary. Instead, each astronaut was assigned a small closetlike enclosure equipped with a zippered sleeping bag.



The food on Skylab was a great improvement over that on earlier spaceflights. No longer was it necessary to squeeze liquefied food from plastic tubes. Skylab's kitchen was so equipped that each crewman could select his own menu and prepare it to his own taste.



Spaghetti and meat sauce came premixed and ready to be heated.

One of the astronauts found that he preferred to sleep upside down with his head at the floor and his feet pointed toward the ceiling. He did this "to keep air from blowing up his nose," which annoyed him when he slept "right side up."

Problems of Waste Disposal

Getting rid of the garbage presented a unique challenge to the Skylab designers. Trash collected quickly and had to be stored securely out of the way to prevent its floating around. Medical experiments required that urine samples be collected and frozen and that solid human waste be dried before return to Earth for examination and analysis of mineral balance by the medical specialists.

Again, the lack of gravity severely complicated Skylab design problems. The system was required to sample, process, and store crew body wastes, including feces, urine, and vomit. Further, it had to provide a means for the crew to perform necessary fecal and urine eliminations, to sample and pre-

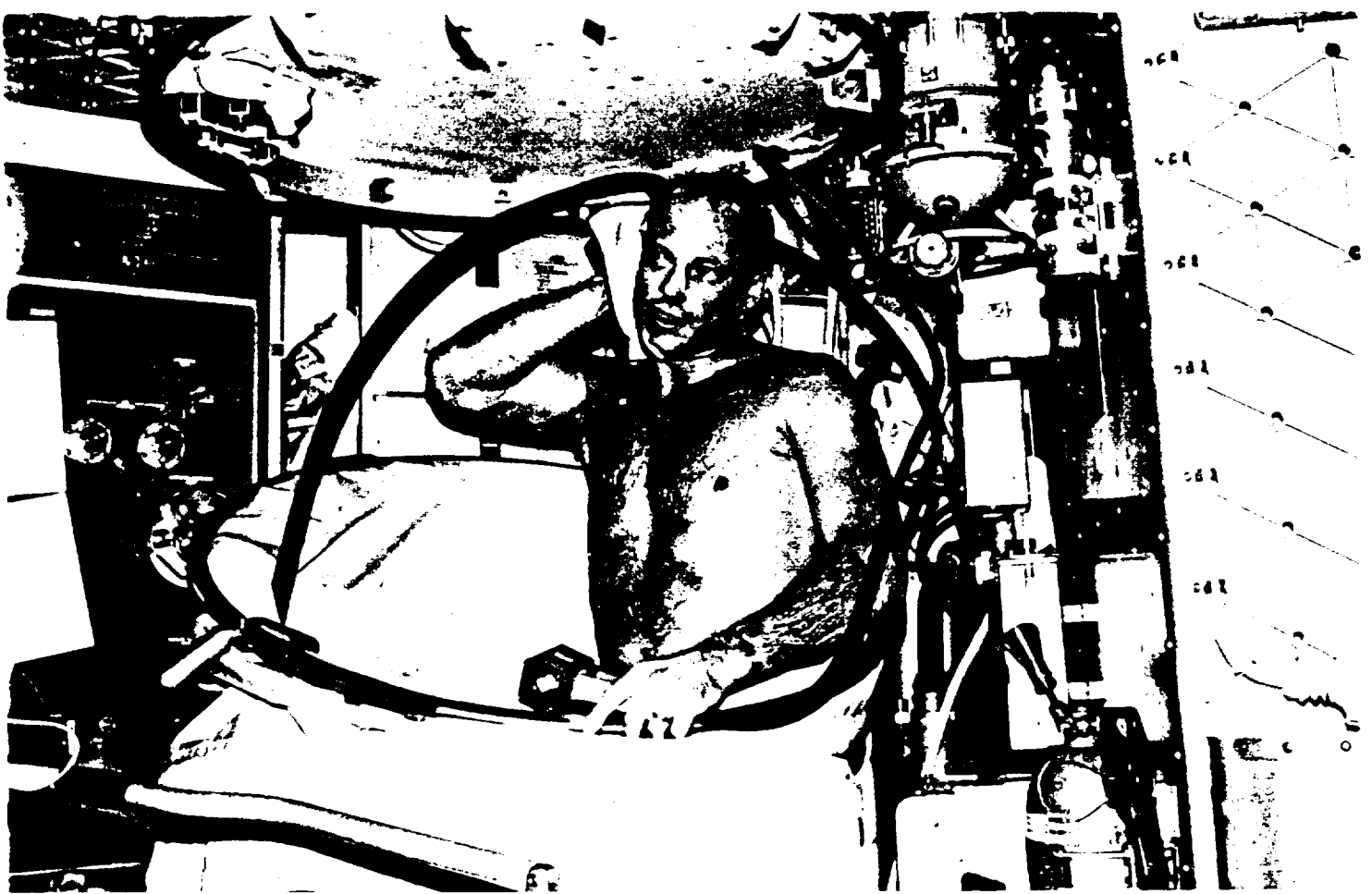
serve the material for biomedical analysis upon return, and to dispose of the remainder.

The system finally designed consisted of a fecal-urine collector, collection and sample bags, sampling equipment, and odor-control filters. The fecal-urine collector used airflow to substitute for gravity in separating the waste material from the body. Urination could be performed in a standing position, and both elimination functions could be performed while the crewman was seated.

Some of the astronauts bathed in a cylindrical



The disposal of body waste was a difficult problem for Skylab's designers. Airflow was used as a substitute for gravity, separating waste from the body and disposing of it in special containers. Samples of collected waste were preserved and returned to Earth for medical analysis.



The collapsible cylindrical shower enclosure was attached to the floor. The astronaut drew it up around him for use. Water was driven into a collection system by airflow. Both water and soap were premeasured for economical use.

shower, with water discharged through a hand-held showerhead. The floating water droplets were drawn into a water collection system by movement of air.

Both spring-wound and standard safety razors employing shaving cream were used for shaving.

Crew health and safety, always a major consideration in manned spaceflight programs, presented some particularly difficult design hurdles. Areas of special concern were the effects of radiation, contamination, and the selection of materials with potentially harmful properties such as flaking or the generation of undesirable gases.

Control of Radiation and Contamination

With a total mission of nearly 9 months, one of the most significant concerns was for the effects of exposure to prolonged space radiation on com-

ponents, materials, sensors, measurements, but most especially on the crew. A radiation hazard analysis, performed with a computerized mathematical model to determine the expected radiation levels for the planned manned missions, showed that the maximum expected radiation doses were well within safe limits. Further analyses on equipment showed that, with the use of protective equipment such as vaults for film storage, the potential effects of radiation would probably be negligible.

Contamination had been a problem on many satellite and earlier manned space programs, degrading performance of critical experiment surfaces or even causing major system failures. Because of the expected long duration of the Skylab mission with its many sensitive optical experiments, and with man as one of the major contamination



The astronauts used both spring-wound and safety razors for shaving. Pilot Lousma is shown here.

sources, a significant effort was required to keep contamination to a minimum.

The environment surrounding Skylab at its orbital altitude was composed of the very thin Earth atmosphere along with molecular and particulate matter produced by the space station itself. This induced environment was dynamic and resulted from materials outgassing and overboard venting from the operational activities.

Material from the induced atmosphere which deposited on Skylab surfaces altered surface characteristics and could have adversely affected sensitive instrumentation. Such deposited material could have also altered transmission and reflection characteristics of optical surfaces, changed the absorptivity and emissivity of thermal control surfaces, and altered the resistance of electrical connections.

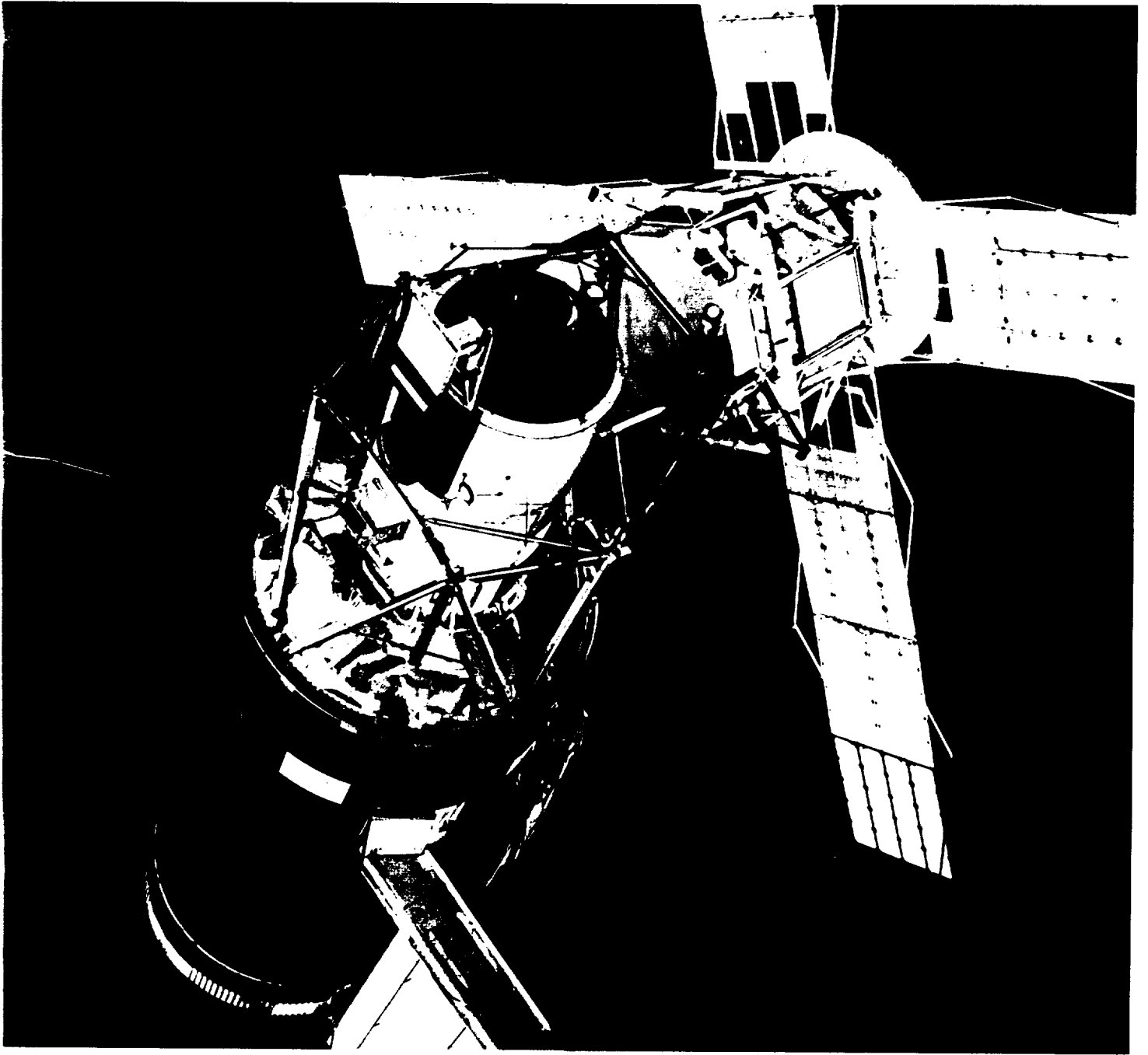
As the sources of contamination were identified during the design phase and the effects on susceptible experiments and surfaces were understood, various control measures were established. Wherever possible the sources were eliminated, experiments and windows were kept covered when not in use, and the sequence of operational activities during the mission was planned to keep contamination-generating events from occurring when a sensitive instrument was exposed.

Skylab Materials

Materials used in the crew quarters and for the external Skylab structure were carefully selected to be compatible with the expected environments, including wide temperature ranges. The space-vacuum conditions required that the materials be stable from the standpoint of outgassing or volatility which could lead to contamination of optical apparatus and other experiments. The intensity of ultraviolet radiation from the Sun dictated use of protective thermal control coatings.

The high oxygen content in the crew quarters enhanced the flammability potential. For that reason, the use of flammable materials was severely restricted, and each specific use was identified and mapped. Special precautions were taken to insure that no ignition sources existed.

Many new nonflammable materials were developed during the Apollo and Skylab programs. Some were used for the first time in Skylab. Each material was rigidly screened to insure satisfactory



Some areas on the Skylab exterior became discolored. Engineers attributed this to an interaction between contaminants and solar ultraviolet radiation.

application with respect to outgassing, toxicity, odor, dimensional stability, and chemical stability.

Maintenance and Repair in Space

Initial planning for Skylab envisioned only a limited degree of inflight maintenance. As on previous manned spaceflight programs, dependence was to be placed on components of very high reliability and the use of redundant systems, where necessary. As the program evolved, however, the Skylab systems became increasingly complex. In addition, the manned periods were lengthened, and plans were developed to have the astronauts perform more and more tasks. It became obvious that, even with high reliability systems, failures could occur. And if they did, they could jeopardize mission completion.

Gradually, a concept was developed which called for considerable maintenance to be performed by the flight crew. This concept had certain restraints, however. No maintenance was to be performed during extravehicular activity except for film replacement and pinning open solar telescope aperture doors. This concept was later modified drastically, as extravehicular maintenance activity became necessary for the mission to continue.

Flight and ground crews, working together, demonstrated the wisdom of the provision for inflight maintenance. The extensive training of the flight crews and their knowledge of the Skylab systems enabled them to analyze problems and provide accurate technical data to engineering crews on the ground.

There were three categories of inflight maintenance: scheduled activities for normal cleaning and replacement tasks; unscheduled activities for anticipated repair and servicing of designated equipment; and a general capability for unexpected or contingency repairs.

Scheduled inflight maintenance included periodic cleaning or replacement of consumable, cycle-sensitive, or time-sensitive equipment. Such housekeeping tasks, scheduled in the daily flight plans, included the cleaning or replacement of such items as waste system and environmental control filters. Onboard tools, spares, and procedures were provided for such tasks.

Unscheduled inflight maintenance included replacing failed components, installing auxiliary and backup hardware, and servicing and repairing cer-

tain equipment. Spare components, tools, and procedures were provided for performing over 150 different unscheduled tasks, and the crew was trained to perform each. Task selection was based upon analysis of failure criticality, failure probability, failure effects on the mission and the crew, complexity of the required maintenance, support required, and time to perform the maintenance.

In addition to providing for scheduled and unscheduled maintenance, tools and materials were included for general repairs. Items such as tape, wire, C-clamps, pliers, vise, twine, hammers, and tweezers were included in the tool kit for this purpose. During the mission, additional tools and equipment were launched with the crews to troubleshoot and correct malfunctions for which onboard maintenance support was inadequate. Other contingency situations occurred that were resolved with the onboard support equipment, but required that step-by-step procedures be developed on the ground and transmitted to the crew.

Ground Support

The Mission Control Center, well known for its role in the Apollo program, also served as the control center for the Skylab mission. Engineers and technicians at the Marshall Space Flight Center provided technical support to Mission Control on systems and experiments they had developed. An operations support center at the Marshall center was manned around the clock by specialized engineering support groups involved in Skylab.

These technical groups were kept informed continuously. Data describing the condition of systems aboard Skylab as well as the results of scientific observations were transmitted regularly from the orbiting spacecraft to remote ground sites, and then to the NASA centers at Houston and Huntsville.

Debriefings of the crews also provided much valuable technical information. The astronauts were highly trained, technically knowledgeable men. They had been well schooled in operation of the Skylab systems, so they could quickly detect abnormalities and describe them to the ground crews. Frequent inflight debriefings included both live and recorded conversations, both in response to specific questions and simply to relate observations and experiences. And when each crew returned, the astronauts participated in a series of

extensive debriefings which provided still more valuable information on Skylab's operating condition.

The duration and complexity of the Skylab mission and unexpected problems which developed required continuing support from mission operations and engineering ground teams. Most of the NASA and contractor engineers were veterans of Apollo and earlier manned spaceflight programs, and their experience proved to be invaluable.

Daily flight plans were transmitted to the crew, identifying all activities to be performed, along with time allocations. But adjustments to daily activities were made when equipment problems occurred, when weather conditions precluded performance of a given experiment, or when other problems arose. Such additional tasks as observations of Comet Kohoutek were included. Crew motion sickness, experienced temporarily by some crewmembers, required some adjustments in planning. These and other factors dictated a need for great flexibility in ground support throughout the mission.

Mission operations support teams were located throughout the United States at NASA centers, contractor facilities, and universities. They were called upon to provide around-the-clock support for planning each day's activities and to provide technical analysis and coordination when problems occurred. The most dramatic example was the combined support of many Skylab participants working against time to solve the high temperature inflicted on Skylab with the loss of the meteoroid shield. But there were other problems that constantly were being analyzed throughout the entire mission and required total dedication of all involved to assure successful mission continuation. Such items as management of electrical power use as a result of the temporary loss of one of the two main sources, potential loss of attitude control gyroscopes, and the possible need of a rescue mission for the second crew when leakages occurred in the command and service module attitude control system presented a constant challenge to ground engineering personnel. Time was always a critical factor.

Skylab Crews

Nine astronauts lived and worked in Skylab, and six more astronauts were also involved as backup crewmen to the primary flight crews. The com-

mander and pilot of each primary crew were trained spacecraft and aircraft pilots with strong engineering backgrounds. The scientist pilot was a rated jet pilot as well as a scientist.

The first crew consisted of Comdr. Charles Conrad, Jr., Pilot Paul J. Weitz, and Scientist Pilot Joseph P. Kerwin. Conrad was a U.S. Navy captain who had become an astronaut in 1962. He had been in space before on the Gemini 5 mission, in 1965, and the Gemini 11 flight, in 1966. In 1969, he became the third man to walk on the Moon as commander of the Apollo 12 mission. Weitz was a commander in the U.S. Navy, and he became an astronaut in 1966. He had not previously been in space. Kerwin, also a commander in the U.S. Navy, was a doctor of medicine who had been selected as an astronaut in 1965. He had not flown in space.

The commander of the second Skylab mission was Alan L. Bean, a captain in the U.S. Navy, who was named an astronaut in 1963. Earlier, he had flown in Apollo 12 as the lunar module pilot in 1969. Pilot Jack R. Lousma, a major in the U.S. Marine Corps, joined the astronaut ranks in 1966. Scientist Pilot Owen K. Garriott was a civilian who held a Ph.D. in electrical engineering and became an astronaut in 1965. Neither Lousma nor Garriott had flown in space.

None of the three members of the third crew had flown in space before. This crew was headed by Comdr. Gerald P. Carr, a lieutenant colonel in the U.S. Marine Corps, who had been appointed an astronaut in 1966. Pilot William R. Pogue, a lieutenant colonel in the U.S. Air Force, had become an astronaut in 1966. Scientist Pilot Edward G. Gibson, a civilian with a Ph.D. in engineering and physics, had been named an astronaut in 1965.

Assisting these astronauts during their training, and trained to take over for them in case something happened, were two backup crews.

For the first mission, the backup men were Russell L. Schweickart, a civilian, who had joined the astronauts in 1963. He had been the lunar module pilot for Apollo 9 in 1969. Schweickart was assisted by Bruce McCandless II, a lieutenant commander in the U.S. Navy, who had been appointed an astronaut in 1966. The third member of the team was Story Musgrave, a civilian and a doctor of medicine, who had been selected as an astronaut in 1967. Neither McCandless nor Musgrave had spaceflight experience.



The Skylab prime crews

The second and third missions had the same backup crews, and none of them had previously been on a space mission. They were Vance D. Brand, a civilian who became an astronaut in 1966; Don L. Lind, a civilian, with a Ph.D. in physics, who joined the astronaut corps in 1966, and who also had a scientific experiment aboard Skylab; and William B. Lenoir, a civilian with a Ph.D. in electrical engineering, who became an astronaut in 1967.

Preparations for Launch

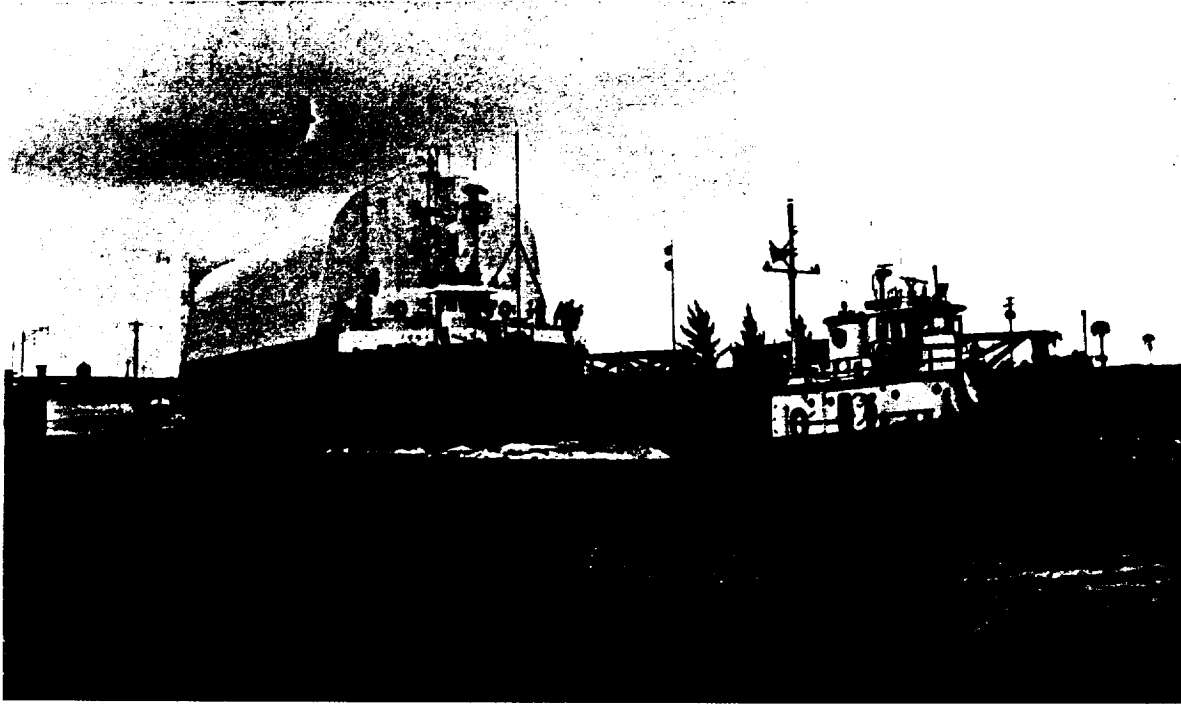
It was May 14, 1973.

Just 3 months earlier, the components standing on the launch pad had been housed in the giant

Vehicle Assembly Building at the Kennedy Space Center. There they had been subjected to a series of tests before movement out to the pad. All possible tests were conducted within the enclosed building before moving Saturn and Skylab outside for special testing and servicing before launch.

Major elements of the Saturn V rocket and the Skylab had been brought to the Kennedy Space Center on Florida's east coast much earlier. Specially designed barges, with environmentally controlled hangarlike enclosures, transported the large Saturn stages. The Super Guppy, an awkward-looking airplane designed especially for the purpose, transported smaller, but still large by most standards, space station and Saturn V components.

The three Skylab prime crews and their backup

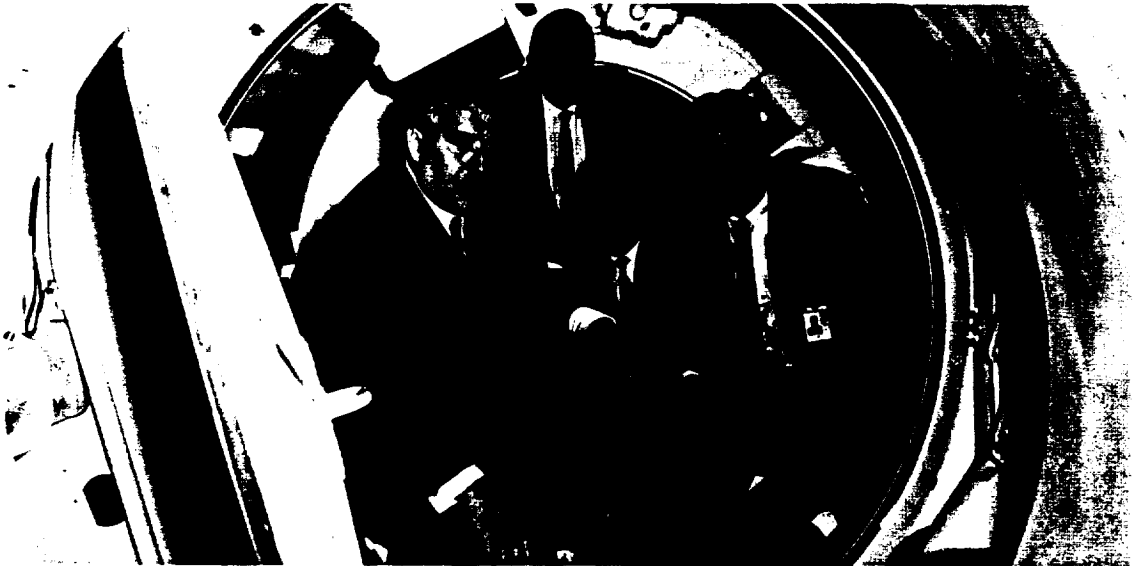


Many of the Saturn and Skylab large components were transported to the launch center aboard special barges or in special modified aircraft.

crews had completed one of the most intensive training programs ever devised. Each had taken an active part in the development of their space station through a series of briefings and reviews, accompanied by individual study and trips to the contractors' plants. They were intimately familiar with the workshop and all its elements. They had undergone extensive training on Skylab systems. Each crewman had received practical training in the diagnosis of illnesses of an outpatient nature and had been schooled in therapeutic procedures for the treatment of illnesses and accidents. Full mission simulators, experiment task simulators, and various engineering development simulators had been used by the crews to rehearse and practice each procedure they would have to follow. Full-scale mockups had been employed extensively for experiment training, procedural and timeline development, conducting stowage exercises, performing procedures, and especially for performing tasks associated with extravehicular activities.

The neutral buoyancy tank at the Marshall Space Flight Center had been used for zero-gravity training, to prepare the crewmen to perform assigned extravehicular tasks, such as the installation and retrieval of film magazines. This training was to prove especially useful when it became necessary to repair the crippled space station.

Finally, as an added precaution, provisions had been made for rescue of a crew, if it had been needed. A rescue kit was available for the modification of a command and service module to receive the extra passengers and return them to Earth safely. And the Skylab crews had been given special training in the procedures necessary to effect safe recovery of their fellow astronauts. A number of significant problems were encountered, but the design of the Skylab systems, the reliability of the hardware in operation, the training and vast preparations carried out in preparation for the mission, and the skill and dedication of the flight and ground crews eliminated any need for rescue.



In October 1968, Fred J. Sanders, right, escorted Wernher von Braun through the McDonnell Douglas Astronautics Co. plant in St. Louis. Inspecting a mockup of the airlock also were Walter Haeussermann, standing, Jack L. Bromberg, left (behind von Braun), and John F. Yardley, behind Sanders.



During his visit to the Marshall Space Flight Center in June 1967, Vice President Hubert H. Humphrey, as head of the National Aeronautics and Space Council, was briefed on the center's programs, including Skylab, by von Braun.



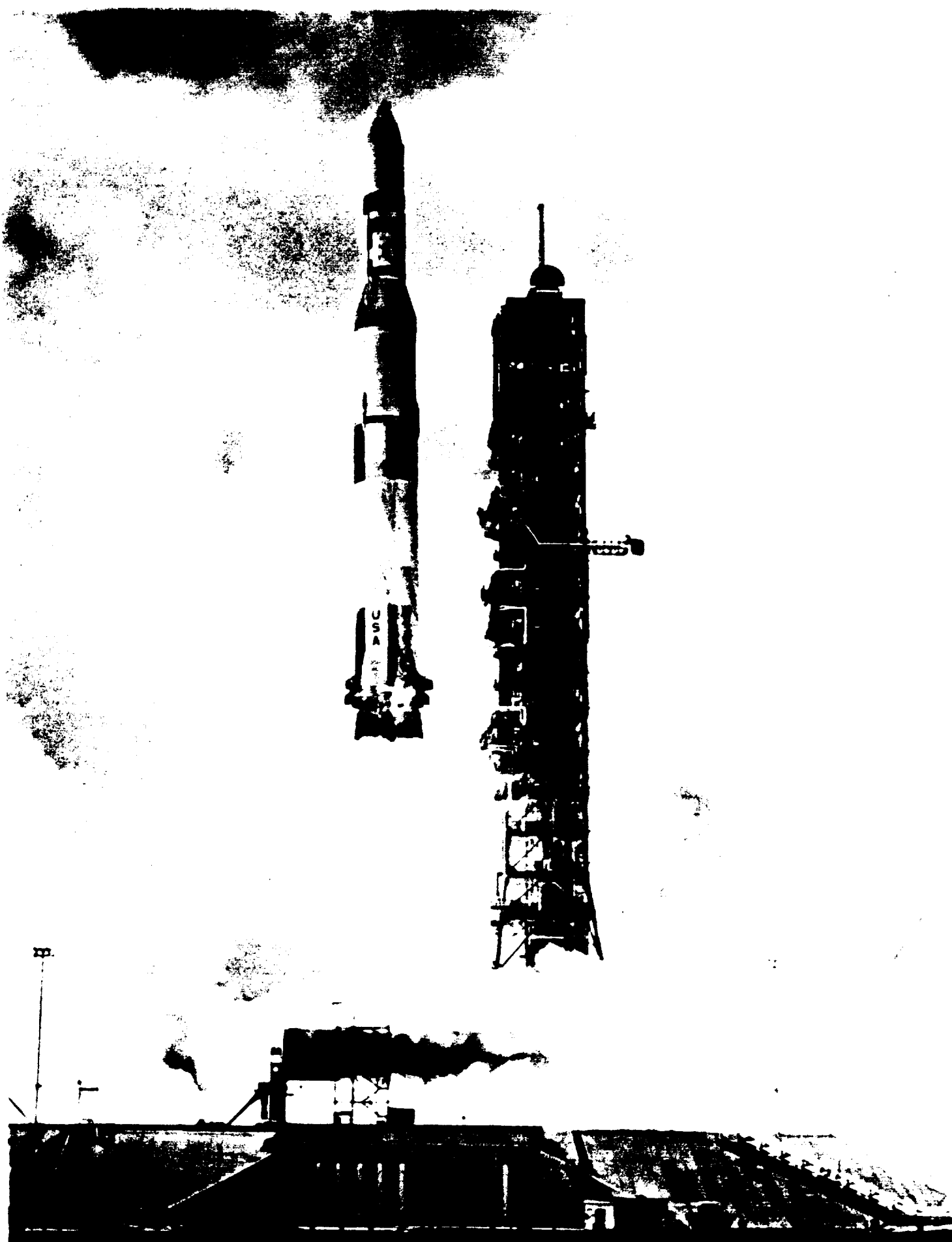
William A. Brooksbank used a model of the orbital workshop to explain its structure and operation to visitors from NASA Headquarters to the Marshall Space Flight Center in December 1967. Seated left to right are Leland F. Belew, James E. Webb, Charles W. Mathews, and von Braun.



In October 1968, von Braun, right, escorted Homer E. Newell through the Skylab mockup at the Marshall Space Flight Center.



NASA Administrator Thomas O. Paine visited the Marshall Space Flight Center in July 1970, for briefings on the developing Skylab program. Shown left to right are Belew, Samuel C. Phillips, Harold T. Luskin, Paine, and Werner Kuers.



3

“We Can Fix Anything”

Skylab's ultimate success contrasted sharply with its almost disastrous beginning.

Flawless and on-time launches of Saturn IB and Saturn V launch vehicles had come to be expected at the Kennedy Space Center. Neither of the rockets had ever experienced failure. Both had played key roles in America's manned space program.

The Skylab cluster which stood atop the Saturn V on the morning of May 14 was complex but thoroughly reliable. Each part was the result of an intensive design and development program, and the product of painstaking fabrication and test.

In the prelaunch tests, Skylab's systems had again been exercised and had performed as expected. The flight-readiness review was conducted to assure that any problems which had occurred in ground test were resolved and no open problems remained.

Now Skylab was ready. Provisioned with supplies for sustaining three crews as they lived and worked for weeks in the space environment, the giant laboratory was posed for flight.

Trouble Began Early for Skylab

Engineers manning the consoles in the control and support centers at the Kennedy Space Center in Florida, at the Johnson Space Center in Texas, and at the Marshall Space Flight Center in Alabama, checked off the key events almost routinely as the countdown continued. And the thousands of NASA and contractor management and technical

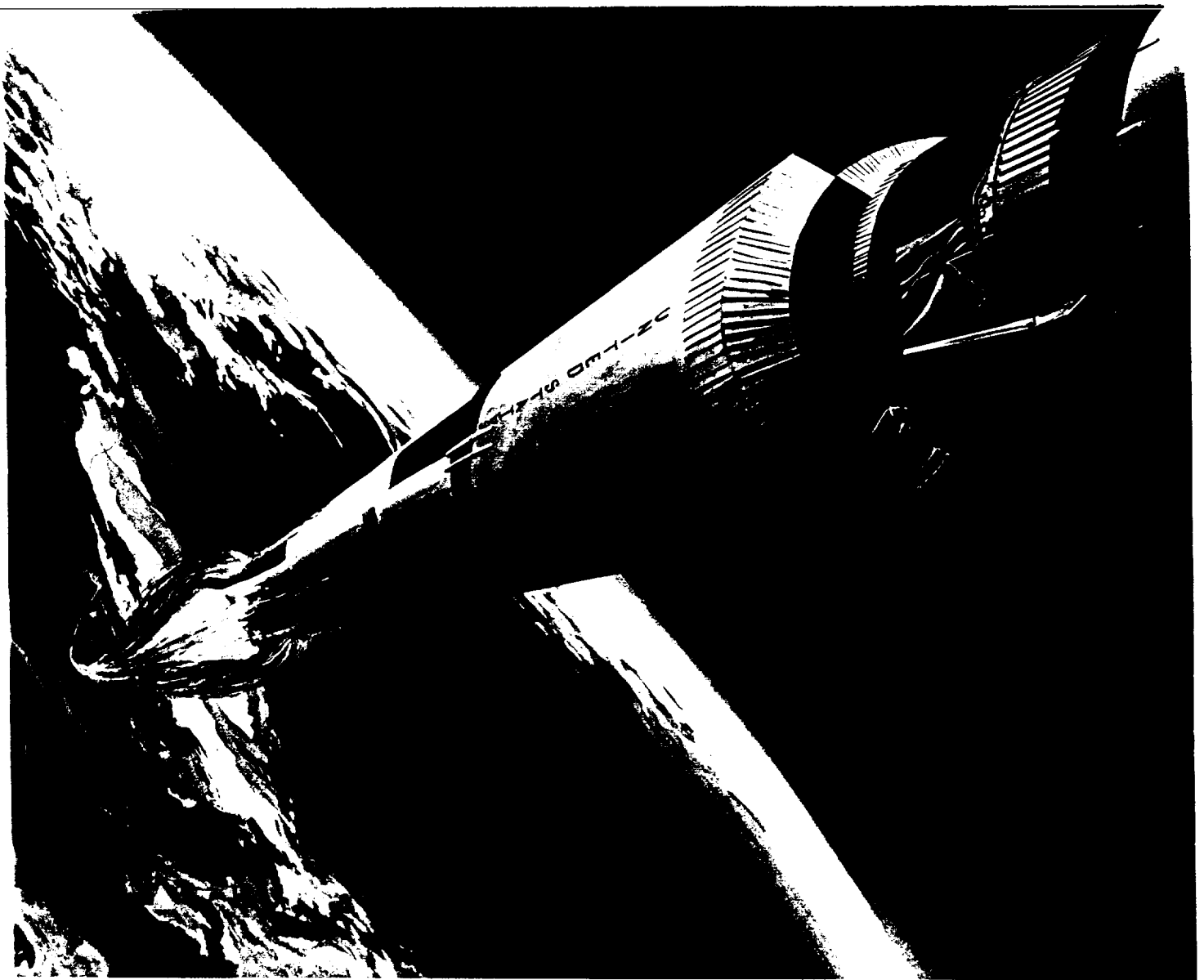
personnel who had lived with Skylab as it evolved from drawing board to launch pad, followed each step, confident that the launch vehicle and the space station would perform as intended.

But this was not to be.

As the moment of launch neared, and the engines on the Saturn first stage thundered into life, no one could have predicted the bizarre series of events that would soon occur.

Precisely on time the huge rocket roared from the launch pad as NASA engineers carefully monitored flight performance. As the great rocket climbed into the atmosphere, all systems performed normally. But suddenly, 63 seconds into flight, engineers manning the consoles were startled to see an unexpected telemetry indication of micrometeoroid shield deployment and initiation of deployment of one of the solar-array beam fairings on the workshop. Also, abnormal micrometeoroid shield temperatures were seen. All other signals indicated a normal flight. Ten minutes after launch, the workshop separated as planned from the second stage. Eight seconds later, the workshop entered its nearly circular orbit above the Earth. Then, a planned sequence of deployment and activation procedures began.

The shield, which protected the refrigeration system radiator from exhaust gases from the rocket motors used during the separation sequence, was jettisoned. The workshop was then maneuvered so that its centerline pointed toward the center of the Earth. With the workshop in this position, the



This artist's sketch of Skylab at 63 seconds after launch shows what apparently happened. During launch, the micrometeoroid shield had torn loose from its position around the workshop and a portion of it jammed one of the workshop solar wings. In so doing, it also severely damaged the other solar wing so that, later in the flight, it tore from its hinges and was lost.

radiator faced away from the Sun's hot rays. The refrigeration system was turned on. Then came jettisoning of the payload shroud, and Skylab was maneuvered to its "solar inertial" attitude.

In that attitude, both solar arrays, the solar observatory and one side of the workshop, always faced the Sun. The centerline of the workshop lay

in the orbital plane while the centerline of the solar observatory, when rotated to its normal position, pointed toward the Sun. Unlike Apollo, Skylab did not roll, but remained in this one position throughout the orbit unless the attitude needed to be changed so that particular experiments could be conducted.

The next planned step in the sequence was to have been deployment of the workshop's winglike solar array, as well as the meteoroid shield which protected the workshop. But as Skylab began to go out of contact with ground tracking stations for the first time, the signal indicating that the micrometeoroid shield was in the deployed position still had not been received.

During the approximately 15 minutes in which there was no communication between ground stations and Skylab, engineers in the flight control centers waited and worried. When communication was resumed, signals should have indicated that the micrometeoroid shield and workshop solar array were in the fully deployed position. Neither of these signals was received. But temperatures on the outside of the workshop were rising rapidly.

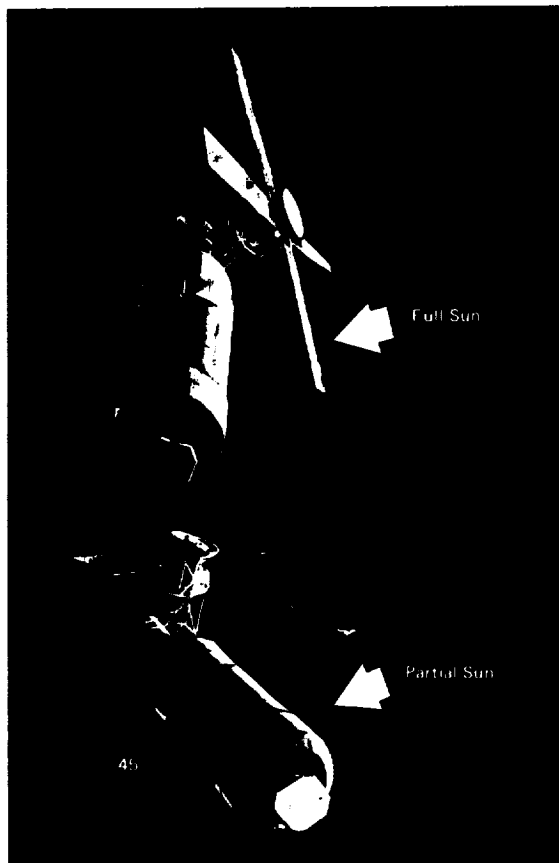
As Skylab passed over Madrid on its second orbit, another command was sent to deploy the workshop solar array. Nothing happened. Later, as the workshop passed over Hawaii, another command was sent to deploy the shield. Again, there were no results.

At this point engineers had concluded, because of high temperatures on the outside of the workshop, and the signals recorded at 63 seconds after launch, that the micrometeoroid shield had been lost. Now the problem became one of protecting Skylab while determining what should be done to save it.

The micrometeoroid shield that was to have protected the workshop was also designed to serve as a heat shield. Black, white, and aluminum paints covered all external surfaces of the shield in a pattern carefully tailored to control heat losses and gains. The outside of the workshop was coated with gold foil, to maintain the required balance of absorption and emission of heat between the shield and the vehicle. Gold foil is a material highly absorbent to solar energy with very low heat loss from reradiation. When the shield was lost, the gold surface of the workshop was exposed to the Sun, and the workshop developed external temperatures about 200°F higher than it had been designed for.

The manned launch, scheduled for the following day, was postponed for 10 days to allow time for analysis of the problem and arrive at a means for overcoming it.

Ten days—and nights—seemed an incredibly short time to determine the exact problem and



Normally, Skylab flew in the solar inertial attitude, with the solar arrays directly facing the Sun. After the micrometeoroid shield was lost, ground controllers maneuvered the space station so that the workshop centerline was at a 45 degree angle to the Sun. The solar arrays then operated with less effectiveness, but temperatures within the workshop were kept at a tolerable level.

devise a reliable means of correcting it so that the mission could continue as planned. But in that 10-day period, teams of engineers all over the country were to correctly assess the problem, design, build, test, and deliver the equipment and tools needed to save Skylab. Under usual conditions, this effort would have required many months.

Each of the participating NASA centers immediately initiated emergency activity. For almost 2 weeks, at these centers and at contractor locations, and at many universities throughout the country,

the lights burned continuously as engineers, scientists, and technicians worked around the clock.

Typical of their activities was a study to predict the effects of the conditions described by telemetered data. From measurements transmitted from Skylab to ground stations, engineers began calculations to determine the temperatures in the film vaults, the food lockers, and the medicine containers. They made investigations to determine the effect that high temperatures would have on the polyurethane foam insulation bonded to the workshop's inner wall. If the temperatures soared too high, they feared that the insulation might separate from the wall, begin disintegration, and give off toxic gases which could be harmful, even lethal, to the crew. High temperatures could also cause the stored food to spoil and the sensitive film to fog.

With no means of shading Skylab from the Sun, ground controllers maneuvered the space station to reduce the effect of the Sun's rays. But each maneuver to bring thermal relief also placed the solar array of the observatory in a position where it was no longer fully effective. The changing position also caused some auxiliary cooling systems to approach freezing temperatures.

It was found subsequently that one of the solar wings on the workshop had been torn away. The other had not deployed fully. All electrical power had to come from the solar array of the observatory. But the array produced full power only when it was perpendicular to the Sun's rays, and it was not possible to keep Skylab in this position because of the need to turn the workshop away from the Sun. Finally, after considerable maneuvering, ground controllers placed the orbiting workshop into a position where it was approximately 45 degrees from the Sun's rays. The solar power production decreased substantially, but temperatures in the workshop did not rise as rapidly.

Finally, temperature inside Skylab was stabilized at approximately 130°F and the power produced by the solar observatory array was about 2800 watts. This barely covered the requirements for operating essential systems such as the attitude control and communications systems. Before the men of Skylab could move in, considerably more power would have to be supplied, and temperatures would have to be reduced drastically.

Of the three kinds of food on board, the dried food was relatively insensitive to high temperatures. Frozen food in the deep freezers was not in

danger, because the refrigeration system worked very well. But canned food could well be affected by high temperatures. However, the food could have been resupplied, if necessary, and preparations were made to replace some of the medicines.

The First 10 Days—A Rigorous Test

Skylab's first 10 days in orbit provided a rigorous test of its attitude and pointing control system.

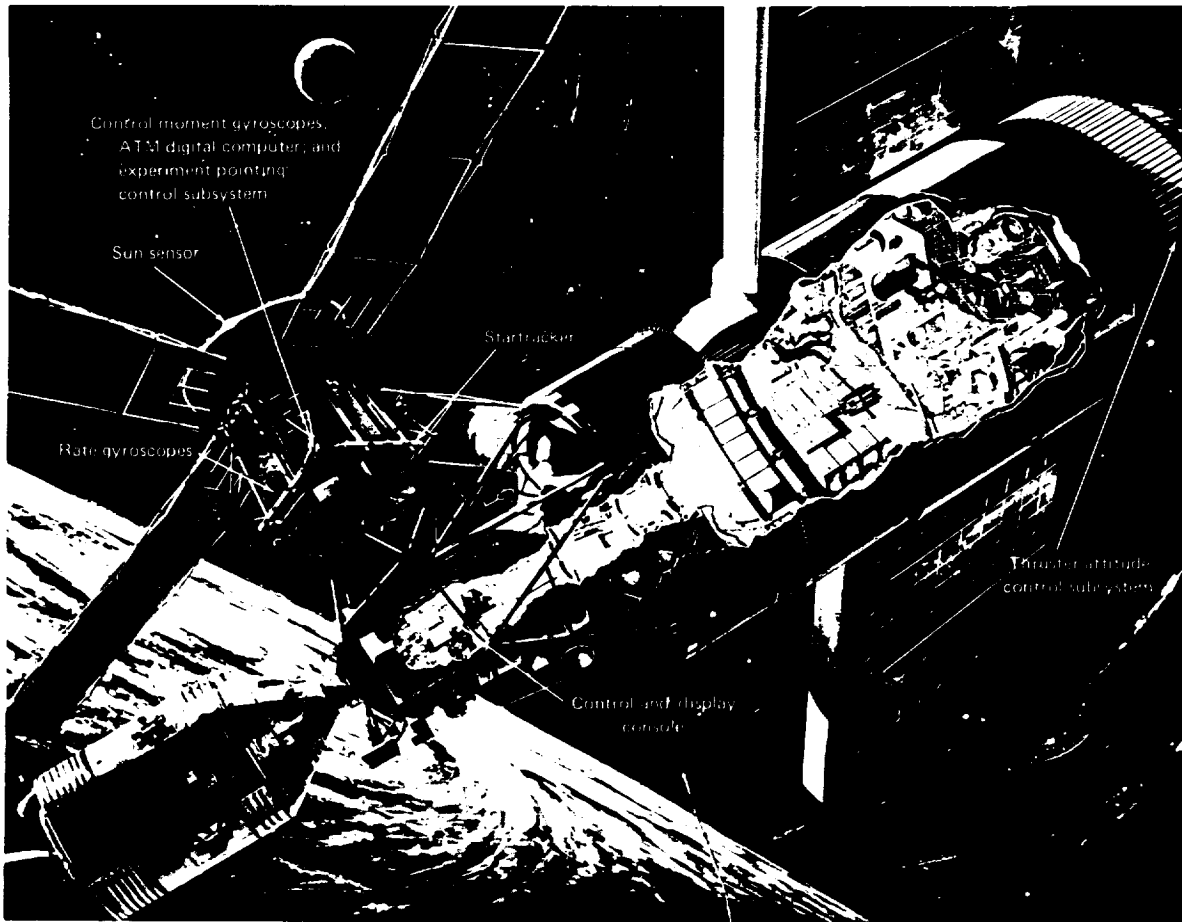
Pointing control means developed for previous spacecraft helped greatly in the design and development of the Skylab attitude and pointing control system. But the size of Skylab, the long mission duration, and the great pointing accuracies required dictated the development of a new system. For example, the system needed would be required to point experiments on the Sun with less than 2.5-arc-second error for a minimum of 15 minutes. This accuracy is the equivalent of holding the sight of a rifle on a target the size of a period from a distance of 100 yards.

The principal device used for maneuvering and controlling the attitude of Skylab was a control-moment gyroscope.

Gyroscopes have been used for many years as error sensors in aircraft and for spacecraft stabilization and control. But large gyroscopes were used for attitude control for the first time on Skylab. These gyroscopes accepted commands from the controller or computer and applied torques to the spacecraft so that Skylab could change its position in orbit as needed.

Each Skylab control-moment gyroscope consisted of a motor-driven rotor, electronics assembly, and power inverter assembly. The 21-inch-diameter rotor weighed 155 pounds and rotated at approximately 8950 revolutions per minute. Rotating the spin axis of the rotor caused the gyroscope to produce a torque or turning moment about an axis perpendicular to both the spin axis and the axis about which the spin axis was being driven. The torque generated was proportional to the rate at which the spin axis was rotated and to the angular momentum of the gyroscope (determined by the spin rate and mass).

Three such gyroscopes were used on Skylab. Any two could provide the torques needed. The third gyroscope added control capacity as well as being a backup, in case of failure of one of the



Attitude and pointing control system

other two. This capability was to prove itself during the third manned period.

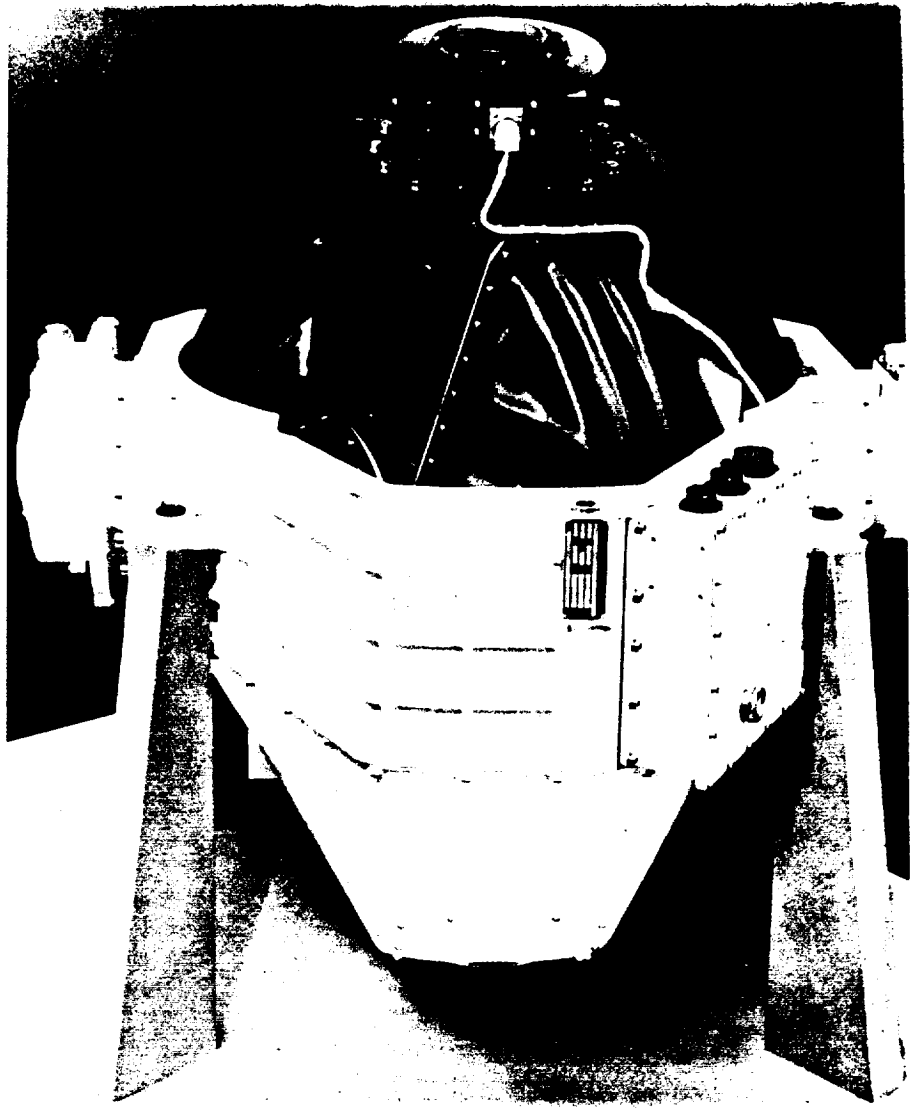
Skylab in orbit needed a reference direction in space to insure that it had the desired angular orientation as it passed any given point in its orbit. This function was performed by Sun sensors, rate gyroscopes, and star trackers. They sensed the angular position and rate of rotation of Skylab with respect to the Sun and selected stars.

Rate-gyroscope processors measured the rate of rotation of Skylab and sent signals to its digital computer. These signals were used in a mathematical computation to describe the space station orientation at any time.

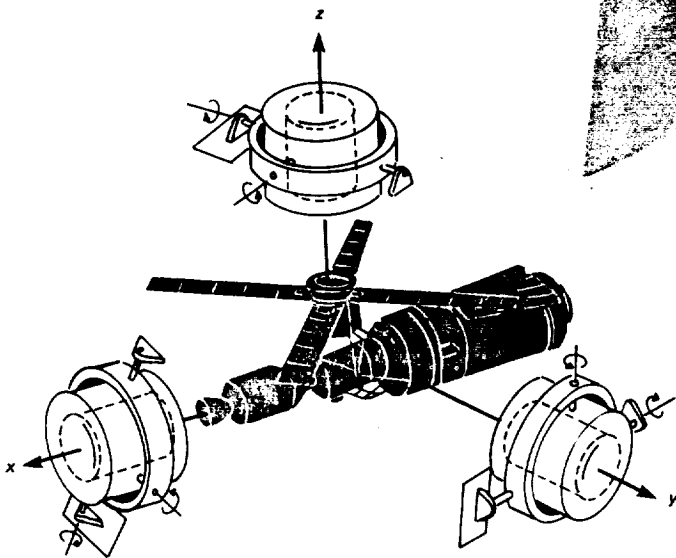
Each of the rate-gyroscope processors consisted

of a single rate-integrating gyroscope connected to electronic devices whose outputs were proportional to the precessional rate of the gyroscope about its input axis. Nine rate-gyroscope processors, three for each Skylab axis, were mounted on the solar observatory support structure. Two gyroscopes in each axis were averaged for control; the third was on standby to be used, if something happened to either of the others. An onboard digital computer monitored these gyroscopes to detect possible failures, isolate problems, and to select new combinations of gyroscopes, if necessary.

Updating, to correct for gyroscope drift, was accomplished by ground command through the onboard digital computer. Contrary to design



Bendix



Skylab was the first spacecraft to utilize very large gyroscopes to control spacecraft attitude and for precise pointing of its instruments for scientific experiments. Three such gyros were used, each of which applied torque about two perpendicular axes.

expectations, most of the rate gyroscopes drifted excessively and erratically at one time or another in the early part of the mission. Such drifts made it very difficult to hold the emergency positions commanded during the first 10 days. Sudden changes in drift rate, which occurred frequently, caused difficulties in Skylab attitude control until the new drift rate could be determined and appropriate compensation made. As the mission continued, the magnitude of the drift rate changes decreased. Eventually, three of the rate gyroscopes became stable.

Also, early in the Skylab mission, some of the

rate gyroscopes overheated and showed a tendency to oscillate. There was concern that the overheating might cause permanent damage, which, with continued use, would result in loss of control. Later, available spare gyroscopes were prepared for flight providing fresh hardware with changes to overcome the problems of overheating and excessive drift. These new units were carried aloft and installed in the docking adapter by the second Skylab crew and performed flawlessly.

In addition to the control-moment gyroscope system, a thruster control system, similar to that used in many of the previous manned spaceflight programs, provided backup control of Skylab's position. It also provided control of the space station during the time when the control-moment gyroscopes were being brought up to speed, normally during the first 10 hours of each mission, and controlled workshop position during docking of the command and service module to Skylab.

The thruster attitude control system had to provide a high thrust level of 50 pounds during separation of Skylab from Saturn V and 20-pound

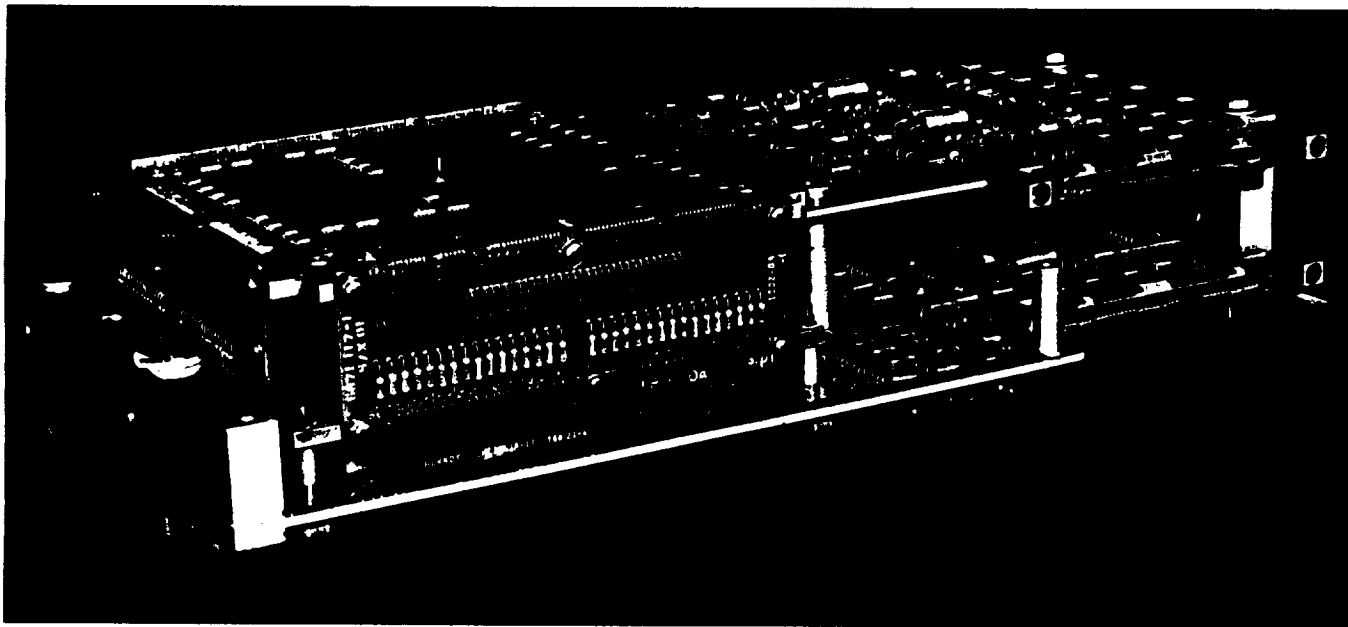
thrust for each of the dockings. The system used the same rate gyroscopes, Sun sensors, and computer as the control-moment gyroscopes.

Nitrogen gas had been used in many previous spacecraft control systems, so little development work was necessary to provide a system with a high degree of reliability.

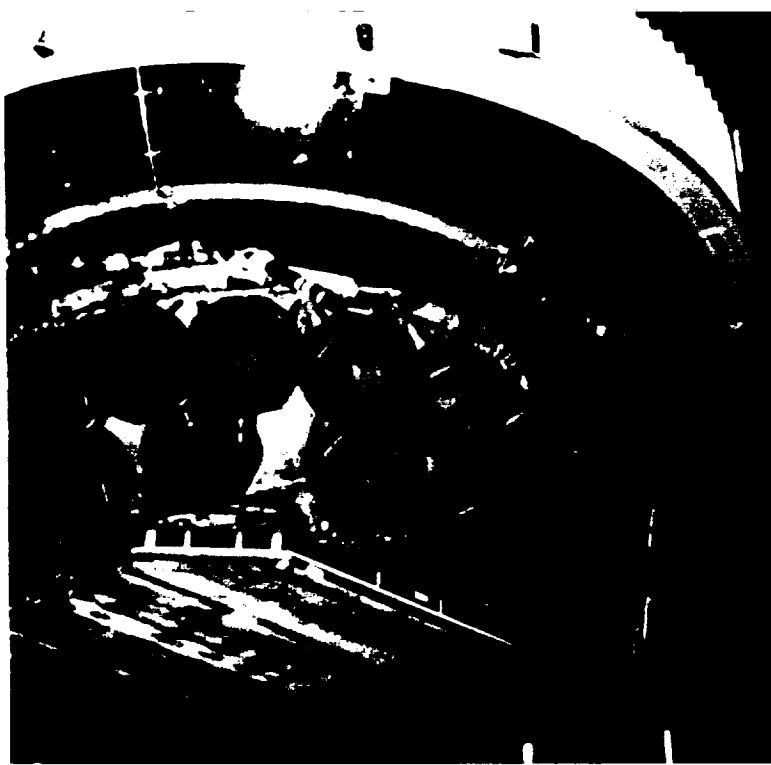
Twenty-two titanium storage bottles, clustered in a ring around the aft end of the orbital workshop, held the nitrogen. This gas was supplied to six thruster nozzles arranged in two three-engine clusters opposite each other on the outside of the workshop. The thrusters received their commands from the onboard digital computers to open valves and release the nitrogen.

Each thruster was fired continuously at least 1 second during "full-on" firings, or in short bursts of from 40 to 400 milliseconds, depending upon the pressure in the nitrogen tanks.

During the first trying days of the mission, this system got a thorough workout. Nearly 50 percent of the nitrogen gas propellant provided for the entire mission was used before the first crew



Miniaturization and modern packaging techniques have made possible very compact digital computers, such as this one used in the Skylab. (INTERNATIONAL BUSINESS MACHINES CORP.)



Twenty-two titanium spheres housed the nitrogen required for operation of the thruster attitude control system.

occupied the workshop. Fortunately, because of weather conditions at the time of loading the propellant, about 25 percent more nitrogen was loaded than had been planned.

Energy From the Sun

Skylab's two separate solar-power generation systems were connected so that power could be transferred in either direction. Each system, when fully operational, was capable of providing 4000 watts of continuous power. While Skylab was unmanned, 3200 watts were required. During preparation for astronaut entry into Skylab and during the rendezvous and docking sequences, the total load requirement increased to 4000 watts. Upon activation of the Skylab by the astronauts, the electrical demand continued to increase until it reached an average of 5800 watts.

The solar observatory electrical power subsystem consisted of a four-wing solar array and 18 power conditioners. Each of the power conditioners included a nickel-cadmium battery, a battery charger, and a load regulator. Electrical energy from each power conditioner was supplied to the source buses in the power distributor, which contained the logic required to sequence the

components in the power conditioners and to provide power to the 11 load distributors, for transmission to operating systems.

Some 165 000 silicon solar cells, each about the size of a postage stamp, were distributed on the surface area provided by the four deployable wings. The cells were divided into 18 groups, each group supplying energy to one of the 18 power conditioners.

To insure the integrity of the battery system for the thousands of charge-discharge cycles to which it would be subjected, it was necessary to limit the amount of energy removed from the battery during each cycle to no more than 30 percent of its capacity (6 ampere-hours). Since the cycle life of the batteries was also influenced by operating temperatures, thermostatically controlled electric heaters and radiant cooling measures were used to control battery temperatures.

The orbital workshop electrical power subsystem consisted of deployable solar wings, one on each side of the workshop, and eight power conditioners, consisting of batteries, battery chargers, and load regulators. Electrical energy from each conditioner was supplied to regulator buses, from which power was transmitted to each of the workshop load buses for final distribution to the loads. Circuit breakers were provided on the workshop control and display panels, as were switches to control load sequencing. A total of about 74 000 silicon solar cells of the same design used in the solar observatory system were arranged in eight groups on the surfaces of the two solar wings. Each group supplied power to one of the eight power conditioners. However, each group of solar cells could be switched to one alternate power conditioner to optimize the use of available power during contingency periods. The solar cell outputs were connected in parallel to the charger and load regulator, as they were in the solar observatory. The Skylab electrical load requirements were supplied as the first priority. The remaining power was used to recharge the batteries.

The eight batteries in the workshop electrical system were slightly larger than those of the solar observatory system. They were also limited to a discharge of no more than 30 percent (9.9 ampere-hours), to insure adequate life to support the mission. Thermistors in each battery provided temperature sensing, load-meter compensation,



Skylab's solar arrays in flight were exposed directly to the Sun's rays. Solar energy was transformed into electrical power for operation of all spacecraft systems. The proper operation of these solar arrays was vital to the mission.

charge control, and protection against excessive temperatures. The cooling system in the airlock regulated the battery temperature. In addition to measurements of the currents, voltages, and temperature of each solar cell group and power conditioner, two state-of-charge meter readings were telemetered for each of the eight workshop batteries so that battery charge-discharge status could be monitored continuously.

Throughout the Skylab mission, the mission support engineering teams kept a close watch on the operation of the electrical power subsystems to detect possible malfunctions, to take immediate action to correct them, and to manage the available power. This involved monitoring scores of voltage, current, and temperature measurements as they were transmitted from the orbiting space station.

The two workshop solar-array wings, mounted on opposite sides of the workshop, consisted of solar panels hinged together in three sets, or wing sections, and folded for launch into a cavity in the underside of a supporting beam. The beam itself,

hinged at the forward end, folded for launch against the side of the workshop over the micro-meteoroid shield. This beam protected the wing from aerodynamic forces during ascent and provided structural support during and after deployment.

Each of the two beams was held flush against the workshop's structural shell during launch and was freed from its attachments by a small explosive charge. The beam was extended into position by an actuator, which consisted of a spring wrapped around a hydraulic piston. Freeing the beam from its attachments allowed the spring to force the beam outward. A latch locked the beam in place when the hinge limit was reached.

Deployment of the solar wing followed. The three wing sections carried by each beam were made up of rectangular panels of silicon cells. Hinges between the panels permitted them to be folded accordion-fashion for storage during launch. Springs in the hinges caused the panels to unfold, extending the wing sections to their full length.

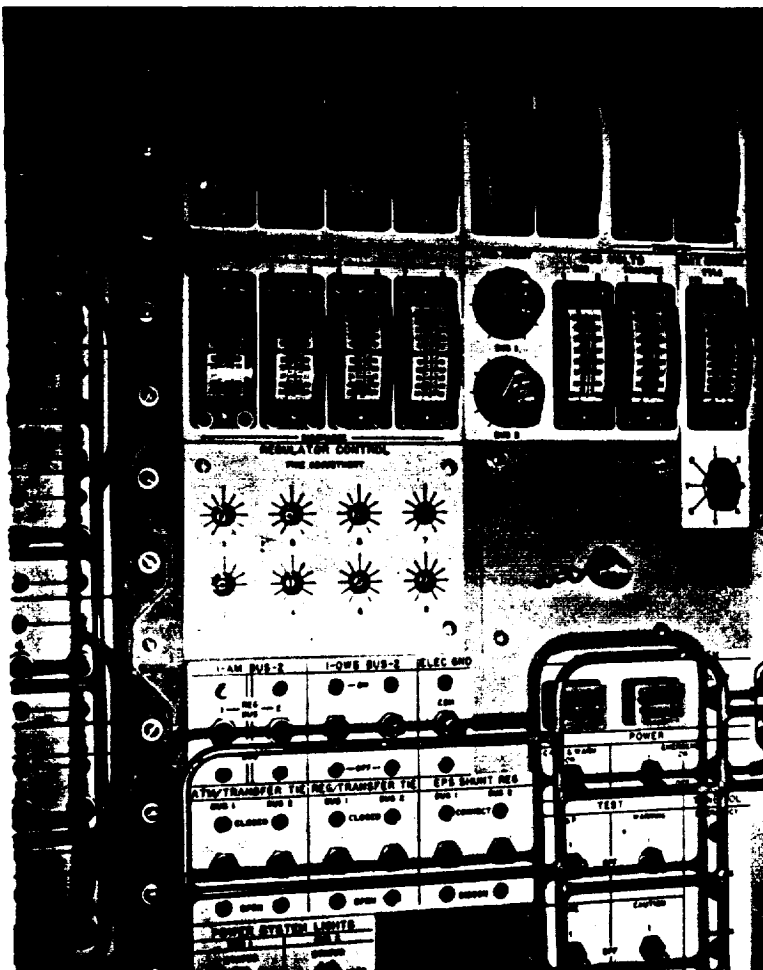
Protection of the Workshop Given Top Priority

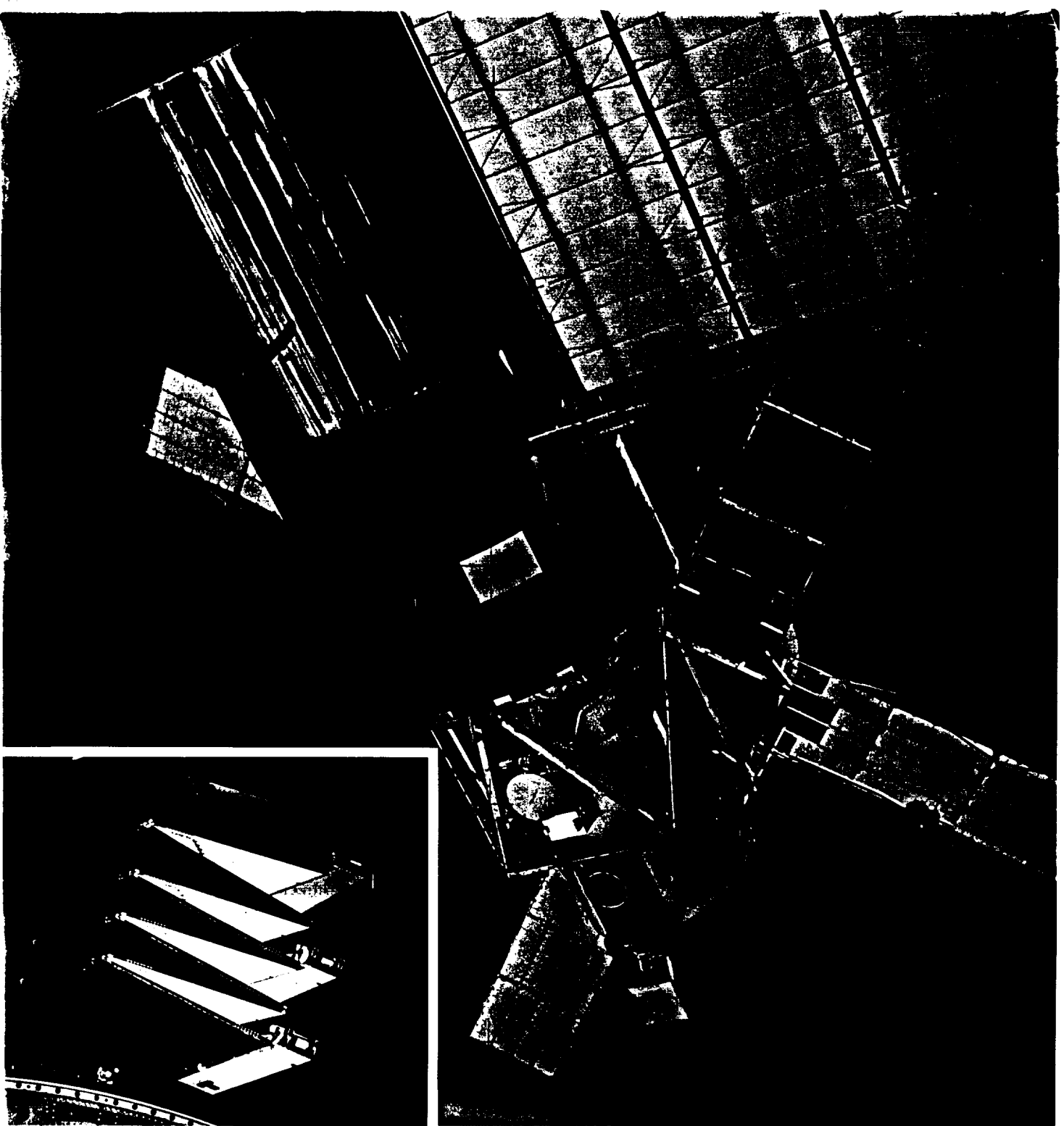
This was how it was supposed to have worked, but now a means had to be devised for shading the workshop and protecting it from the heat generated by the merciless rays of the Sun, while Skylab was reoriented with its solar wings perpendicular to the Sun so that it could generate sufficient electrical power to carry out the mission.

Several schemes were proposed; the scheme selected for initial use involved a square thermal shield which operated like a parasol. This shield fitted into a small canister, originally developed to house an experiment which was to be deployed through a scientific airlock located in the side of the workshop normally facing the Sun. Once outside, the shield popped open like the familiar parasol, with four struts extending outward from a segmented center post. To deploy it, the crew pushed the center post outward a segment at a time, which extended the struts and opened the parasol.

Another concept was to let the crew rig a shield over the workshop while standing in the open hatch of the command module. They would attach ropes to the workshop and thus rig a sail-type shade. This scheme was simple, but it had a serious drawback. It required careful maneuvering to keep the command module close to Skylab while the

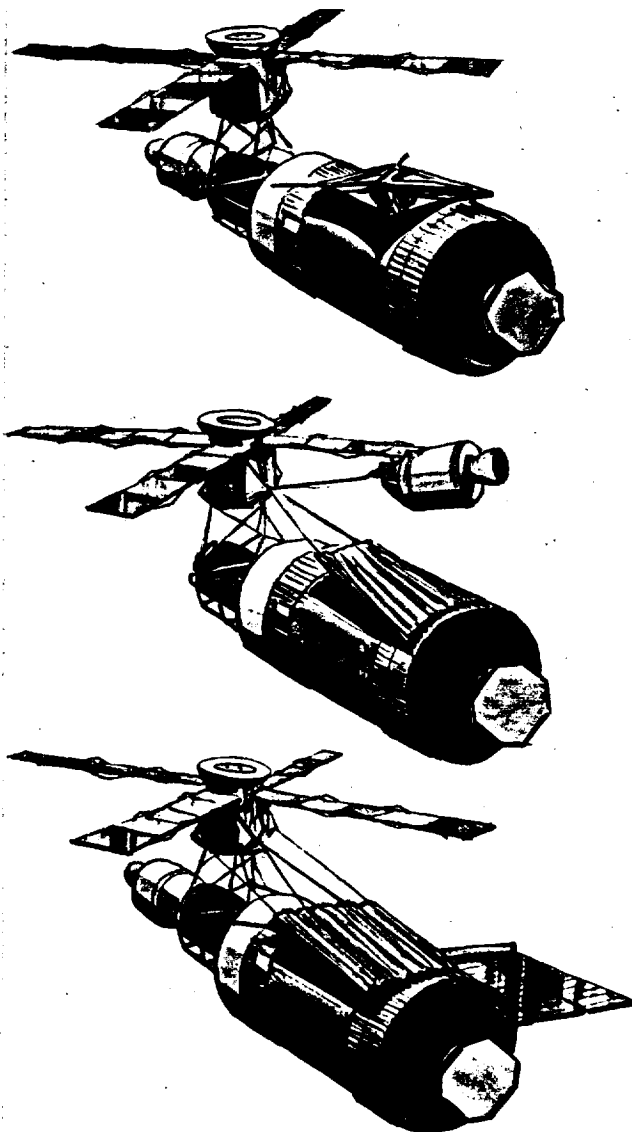
The astronauts could control and monitor the workshop power subsystem by means of the panel shown here.





The partially deployed workshop solar wing was made up of panels which were hinged together. Each was composed of hundreds of solar cells.

The structure of the solar arrays shows clearly in this photograph taken from the command and service module.



With the protective micrometeoroid shield missing, it became necessary to shield the workshop from the Sun by other means. A number of methods were devised, and two were ultimately used. The three sketches show the schemes selected. The upper sketch depicts shading by means of the rectangular parasol, which was deployed from inside the workshop by the first crew. The second concept called for the astronauts to rig a shield from the command and service module maneuvering alongside Skylab. This second concept was not used. The lower sketch shows the twin-pole sail, which was deployed by the second crew during a space-walk.

crew worked to avoid collision of the two. The uncertainty of the crew's ability to tie the shield led to the decision to retain this concept only as an alternative.

Another scheme was later used by the second crew. This "twin-pole" concept also required the astronauts to leave the workshop to hang a fabric awning from a twin-pole frame. The top of the frame was attached to an outrigger on the solar observatory, then 55-foot-long poles were extended down the side of the workshop, and the awning was stretched between them.

Still another proposal called for utilizing the same plastic material of which the Echo satellite was made. It would be formed into an umbrella held in place by inflated balloon ribs that were to be tied to the workshop's structure. Among other concepts suggested, but not used for various reasons, were painting of the workshop exterior, a shield held in place by plastic cords, and a shade produced by inflating a weather balloon.

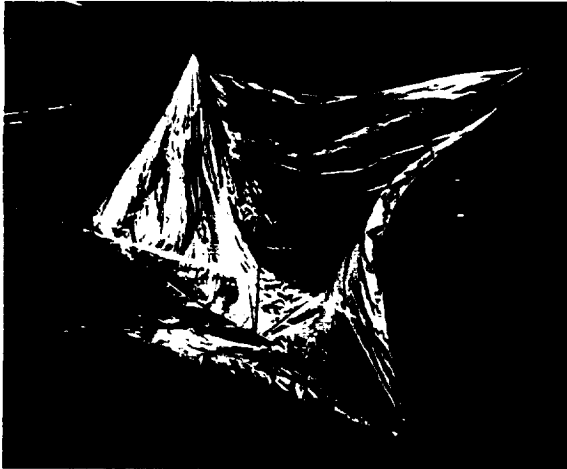
One of the first methods considered for holding down workshop temperatures was to spray the unprotected side of the workshop with a special thermal control paint. The idea was abandoned because it provided a possible source of contamination.

Fabric awnings appeared to be the best answer. Fourteen different materials were tested. The investigations included the effects of ultraviolet radiation, tensile and peel characteristics, stickiness of the materials which might affect the capability to unfold the shield in space, weight changes, possible contamination, and others.

Extensive tests were also conducted on the special radiation-resistant rope to be used with the awning. Nothing was left to chance.

The limited storage space in the command module would accommodate only the three most feasible versions of the thermal shield. The choices were narrowed to the parasol, the twin-pole awning, and the screen deployed from the command module. Development continued, and the astronauts and engineers spent many hours in the neutral buoyancy simulator at Marshall training to deploy the two awnings.

Following a review of all the materials testing, failures, analyses, and deployment procedures associated with the design of the three thermal shields, the parasol was selected as the primary device, since it would not require the astronauts to



The material to be used in the protective shields was carefully selected. It had to be light, very compact when folded, tough and resistant to harmful radiation. Above all, it had to stand up in the space environment for half a year.

venture outside Skylab. The decision was made to deploy the twin-pole awning over the parasol at some later time. It was also to be stowed in the Apollo module as an alternate means of protection.

Meanwhile, a number of other very important problems also demanded immediate solution.

Procedures Developed to Free Solar Wing

NASA engineers were asked to determine what could be done to free the solar wing still pinned to the side of Skylab.

Since there was no way of determining from Earth what was preventing its deployment, all possibilities had to be investigated. One problem almost certainly involved the solar-wing beam's actuator-damper, which operated exactly like an automobile's hydraulic shock absorber. The beam was to be deployed immediately upon reaching orbit. Since that could not be done, the actuator cooled to some -60°F , which was near the freezing point of its hydraulic fluid. There was a high probability that the actuator-damper attachment would have to be broken to permit deployment.

The solar wing sections, which unfolded like an accordion from the beam, also had actuator-dampers. These actuators contained a less viscous fluid than the beam actuator, and they were mounted so that they could be exposed to the Sun

after beam deployment. Thus, Skylab could be maneuvered so that the Sun could warm them enough for the wing sections to deploy.

Speculating that the debris holding the solar wing in place consisted of sheet metal and possibly bolts and small metal straps, engineers at Marshall Space Flight Center concentrated on devising tools which would be manipulated from as far away as 10 feet.

Long-handled tools used by telephone and power companies were adapted for use, and a two-pronged tool designed for prying and pulling was modified to help free the jammed wing. A pulley return mechanism was designed to replace the spring return system on the cable cutters.

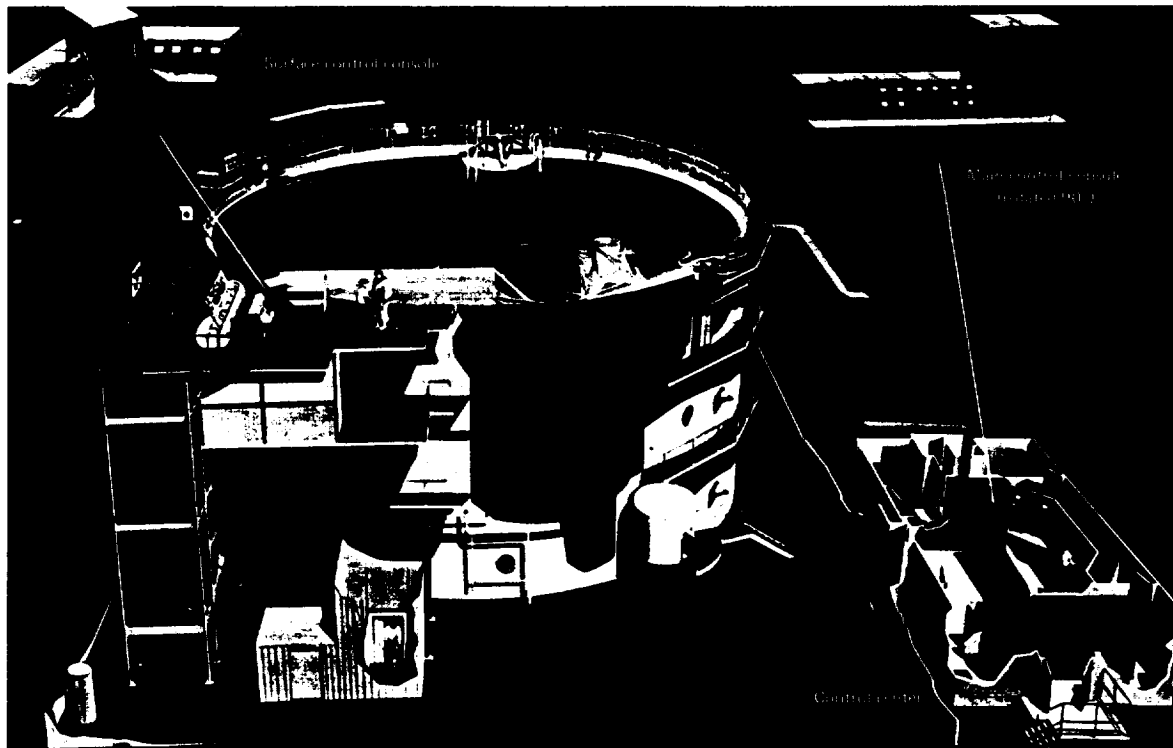
The special tools were quickly fabricated and they were tested in the neutral buoyancy tank which simulated zero-gravity conditions.

On May 19, just 5 days following the Skylab launch, a section of the underwater Skylab mockup was rigged with fragments of metal wire bundles, bolts, and other items representative of the failed shield. This mockup, quickly dubbed "the junk pile," closely resembled conditions which engineers believed the astronauts would find when they reached Skylab.

The first flight crew—Astronauts Pete Conrad,



Special tools were designed and fabricated for cutting the debris holding the workshop solar wing. This is one of the cutting tools, with a special long handle.



The neutral buoyancy simulator at the Marshall Space Flight Center was used extensively to prepare for the mission and during the first month of the flight.

Joe Kerwin, and Paul Weitz—entered the tank to test the tools in the simulated weightless environment. They practiced prying the straps away from the wing, cutting straps with the cutting tools, and moving around the disabled wing safely while performing these operations.

The simulator proved an extremely valuable means for approximating zero gravity. Throughout the mission it was used by astronauts and engineers to train for extravehicular repairs and to develop procedures, and by astronauts and engineers during the missions to conduct “real time” experiments so that they could relay vital information to the flight crews.

The core of this simulator was a 1 300 000-gallon water tank 75 feet in diameter and 40 feet deep. The tank was large enough to accommodate full-size elements of the Skylab. The water was kept clean by a filter, much like that used in a large swimming pool. Integrated into the tank were

special systems for underwater audio and video, pressure-suit environmental control, SCUBA support, and emergency rescue and treatment. Underwater lighting and provisions for communication and data acquisition were also provided.

To simulate weightlessness in the tank, the test subjects and all equipment had to be made neutrally buoyant. This required that the test subject and equipment be the same weight as the displaced water so that they were in a “neutral” state, neither rising nor sinking.

For Skylab extravehicular activity simulations, crewmen wore spacesuits. After the suit was pressurized to match spaceflight conditions, lead weights were then attached as needed to the upper torso, the forearms, and legs until the crewman was neutrally buoyant.

Tools and other equipment were made neutrally buoyant through the addition of flotation units, placed so that the equipment retained its original

center of gravity and so that they would not interfere with equipment operation.

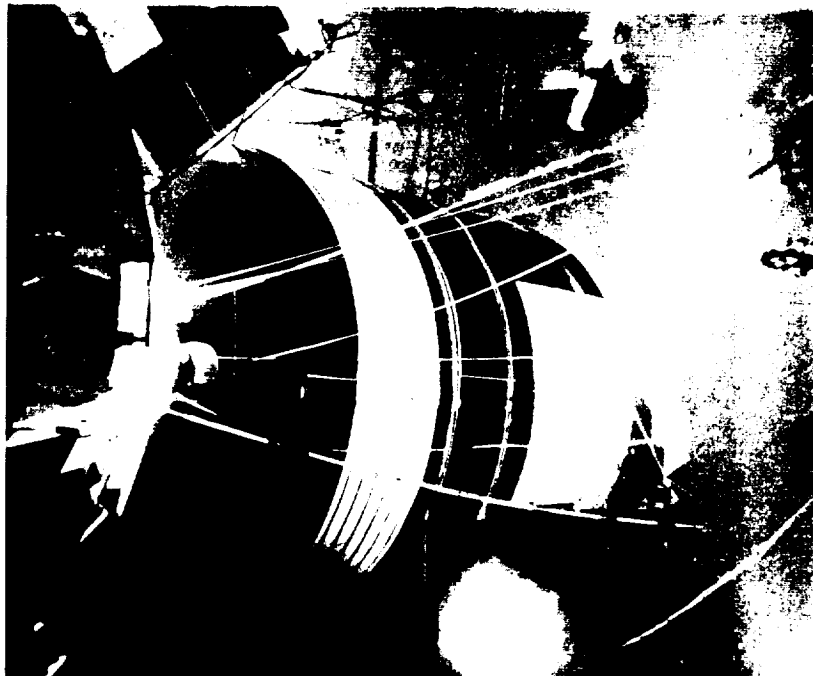
Possible Decomposition of Insulation a Concern

In addition to the loss of the micrometeoroid shield, the apparent loss of one workshop solar-array wing, and the failure of the other to deploy, another serious problem arose. The workshop was insulated with a heavy layer of polyurethane foam bonded to its internal walls, a standard feature of the propulsive upper state. At temperature and pressure conditions similar to those that existed in the workshop, the decomposition of polyurethane creates gases which can be dangerous and even lethal. Extensive and accelerated tests were made to determine the decomposition that might occur at the workshop temperatures in question.

But tests showed that the insulation would not separate from the walls and that there would be no loose particles. However, it was found that appreciable amounts of gases were emitted from the insulation at 300°F. Updated information was obtained from flight data on heat exposures of the vehicle and retesting was begun. These tests showed that even though gas might be coming out of the walls, the volume of the workshop was sufficient to dilute this to acceptable levels.

As a further precaution, ground controllers repeatedly depressurized and repressurized the laboratory with nitrogen to flush overboard any toxic gases it might contain. This pressure cycling continued for 3½ days. As a final precaution, plans were made for the crew to wear gas masks upon entering the workshop and to run gas analysis tests to provide full confidence in the safety of its atmosphere.

Hundreds of scientists, engineers, and technicians continued working around the clock. Many had to be ordered home for much-needed sleep. Meetings were held to determine what simulators and mockups were needed, which thermal models were to be used, when procedures and training facilities were required, which manufacturing personnel were needed, what computer facilities were required, and how crew participation should be scheduled, all in support of the problems being studied. Time went by rapidly. Testing proceeded. When the structural designs were completed, static and dynamic testing was performed. Extensive tests were carried out on workbenches and in the



Rigging of the protective shields for Skylab was rehearsed many times in the neutral buoyancy simulator. Here, a shield made of netting (for simulation only) is being rigged underwater to determine the problems that would be encountered in space.

neutral buoyancy simulator. Finally, difficult choices had to be made.

Besides the thermal shields and tools for releasing the solar-array wing, other new items were stowed in the command module, including additional cameras for the fly-around assessment, equipment for performing the extravehicular activity from the open command module hatch, and equipment for detecting poison gases and protecting the crew from them. Additional drugs, medications, and experiment film were stowed as replacements because of the possibility of damage from the high temperatures in the workshop.

Meanwhile, the schemes devised to hold temperatures down and electrical power at an acceptable level were working very well. Available power was strictly allocated, and, as far as possible, systems using it were turned off or operated intermittently. Heaters, one coolant pump, and telemetry transmitters, for example, were cycled on and off or were operated at reduced loads. The electrical power systems themselves were also managed to check out and protect the systems. The two major problems, high workshop temperatures and a general electricity shortage, still existed. But Skylab was still functioning as Conrad, Kerwin, and Weitz took their places in the Apollo



In this photograph, an engineer tries out a tool developed for freeing the metal strap holding the workshop solar wing. Such tools proved successful in space.



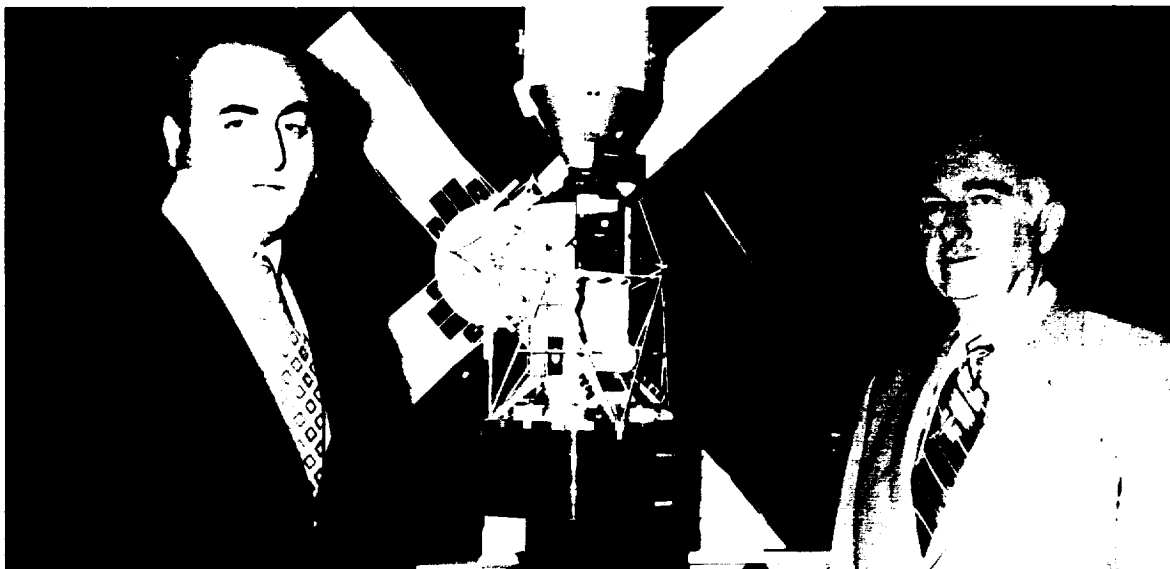
Each of the tools was carefully tested by engineers or astronauts in the neutral buoyancy tank. Techniques for operating the tools were devised.

capsule atop the Saturn IB rocket on the morning of May 25.

The crew was confident that they could restore the damaged Skylab to full operating condition. The problems were staggering, and there were

many unknowns. But the crew was experienced, well trained, and highly motivated.

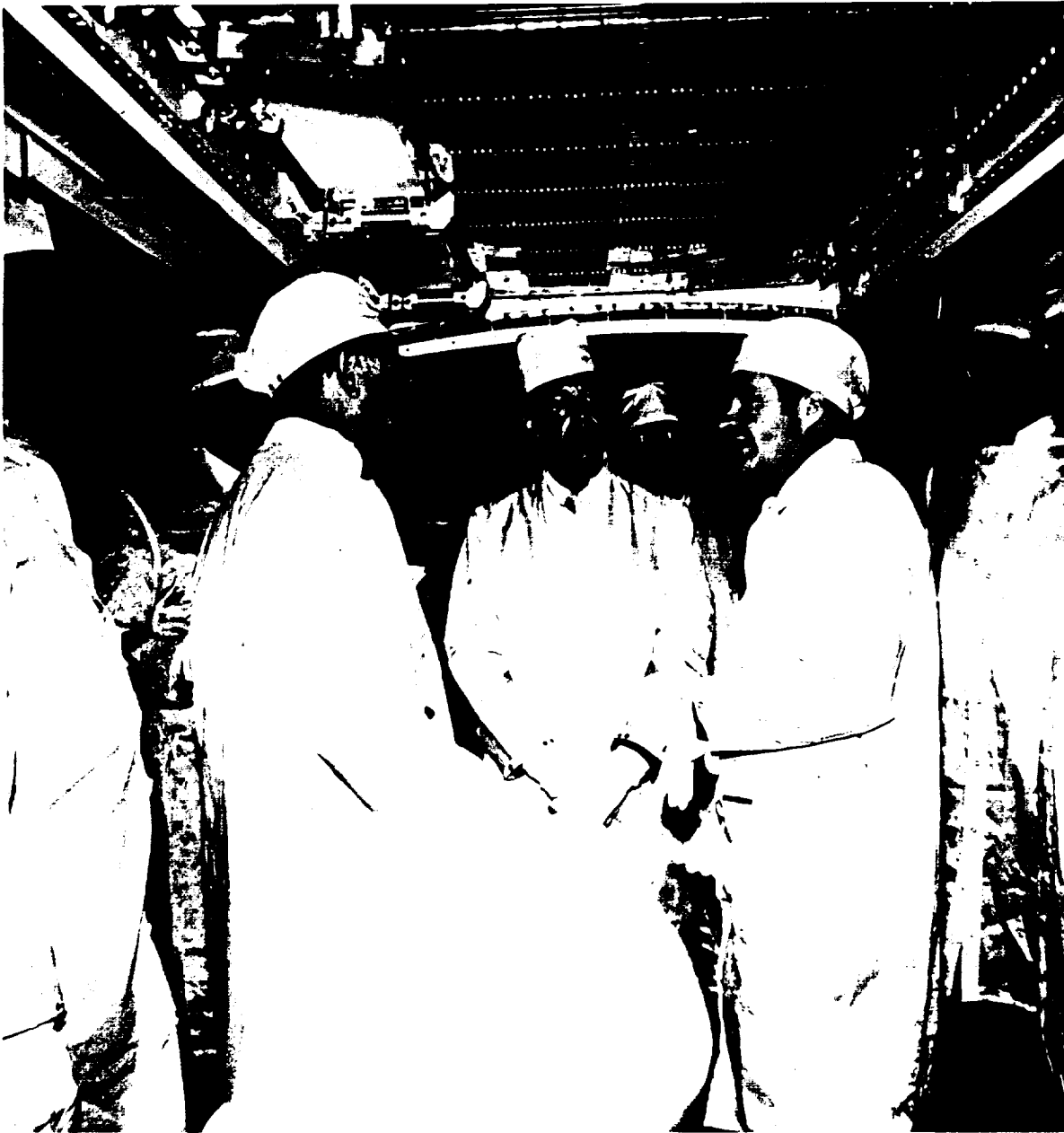
"We can fix anything," they boasted, as the Saturn roared into space. This statement was soon to be tested.



Newsman Walter Cronkite, right, was given a premission briefing by Rocco A. Petrone during a visit to the Marshall Space Flight Center.



Discussing the twin-pole Sun shield for Skylab during tests at the Marshall Space Flight Center were, left to right: Alan L. Bean, Petrone, William R. Lucas (standing), Edward G. Gibson, and Richard T. Heckman.



In June 1973, NASA management reviewed the procedures planned for releasing the jammed orbital workshop solar array. Shown here at the Marshall Space Flight Center are, left to right, Kurt H. Debus, Petrone (partially hidden), Dale D. Meyers, George M. Low, Charles A. Berry, Donald R. Bowden, Kenneth S. Kleinknecht, and Russell L. Schweickart.



4

Rendezvous and Repair

In the afternoon of May 25, as the command and service module orbited over Guam, Mission Control in Houston heard Comdr. Pete Conrad call out:

"Tallyho, the Skylab. We got her in daylight at 1.5 miles, 29 feet per second."

Sighting occurred some 8 hours following a perfect launch that morning from the Kennedy Space Center.

Skylab Condition Predicted Correctly

As the command module closed the distance separating it from Skylab, television cameras relayed pictures to Mission Control, and the flight crew continued its description of the space station.

"As you suspected, solar wing 2 is completely gone off the bird. Solar wing 1 is, in fact, partially deployed . . . there's a bulge of meteorite shield underneath it in the middle, and it looks to be holding it down. It looks, at first inspection, like we ought to be able to get it out."

As they maneuvered for a closer look at the damaged workshop, they reported that the gold foil cemented to the skin of the space station appeared to have been discolored by solar radiation. They also reported that the scientific airlock, through which the parasol shield was to be deployed, was clear of debris.

Initial reports also confirmed that a strap containing a row of bolts, apparently from the micrometeoroid shield, was wrapped around the

solar-wing beam, preventing it from being deployed.

When the first flyaround inspection was completed, the command module docked to the Skylab's docking adapter. Joining the space station relieved the crew of the necessity to "station keep" (fly in formation with Skylab).

While ground crews studied Skylab photographs made from the television monitor, the astronauts ate their first meal, and Conrad commented on the food.

"Dinner's going pretty good, except that Paul found another one of those tree trunks in the asparagus. I had stewed tomatoes for lunch. It turned out that even as goopy as they are, they were real simple to handle, and the same way with turkey and gravy."

When preparations were complete, the crew "undocked" the command module for their first try at orbital repair. As Conrad maneuvered the spacecraft, Weitz leaned out its open hatch with Kerwin holding his legs. Using a 10-foot pole with a hook on the end, he attempted to pry loose the solar-wing beam.

"The tiny little strap . . . so hard that the screws in it just riveted into the SAS (Solar Array System, pronounced *sass*) panel. We pulled as hard as we could on the end of the SAS panel," Weitz reported. "We couldn't get it out right now. We're all trying to break it loose. It's only a half inch strip, but man, is it riveted on!"

Each time that Weitz tugged on the strap, the



During the flyaround inspection of Skylab, Conrad reported: "Solar wing 2 is completely gone, and solar wing 1 is partially deployed." He also reported that debris from the micrometeoroid shield was jammed around the partially deployed wing, holding it in place and preventing full deployment.

Apollo drew closer to the Skylab. Conrad, at the controls, had to keep backing it away to avoid a collision. This movement disturbed the position of Skylab, and caused the thruster attitude control system to operate, using a large amount of nitrogen to maintain stability.

In spite of repeated attempts to bend the strap back from the wing, it refused to budge.

As the spacecraft began to pass into orbital night, the crew reluctantly closed its hatch and maneuvered once more to dock with Skylab. This time, there was trouble. The probe capture latches failed to engage. Conrad backed the command module away and then tried again. No luck. Several

attempts were made, but none of them proved to be successful.

Finally, the crew put on their spacesuits, depressurized the command module, removed its forward hatch, and disassembled part of the docking probe. Then they tried again, and now the latches worked. With the command module securely coupled to Skylab, the astronauts slept for the first time.

When they awakened, they would enter Skylab and determine what damage the searing heat of the Sun had caused to the interior of the workshop.

Would the temperatures they found be too high for them to work in? Would they find toxic gases from overheating of the insulation?

Solar wing 1 was held firmly in its partially deployed position by a strap, apparently from a portion of the micrometeoroid shield.



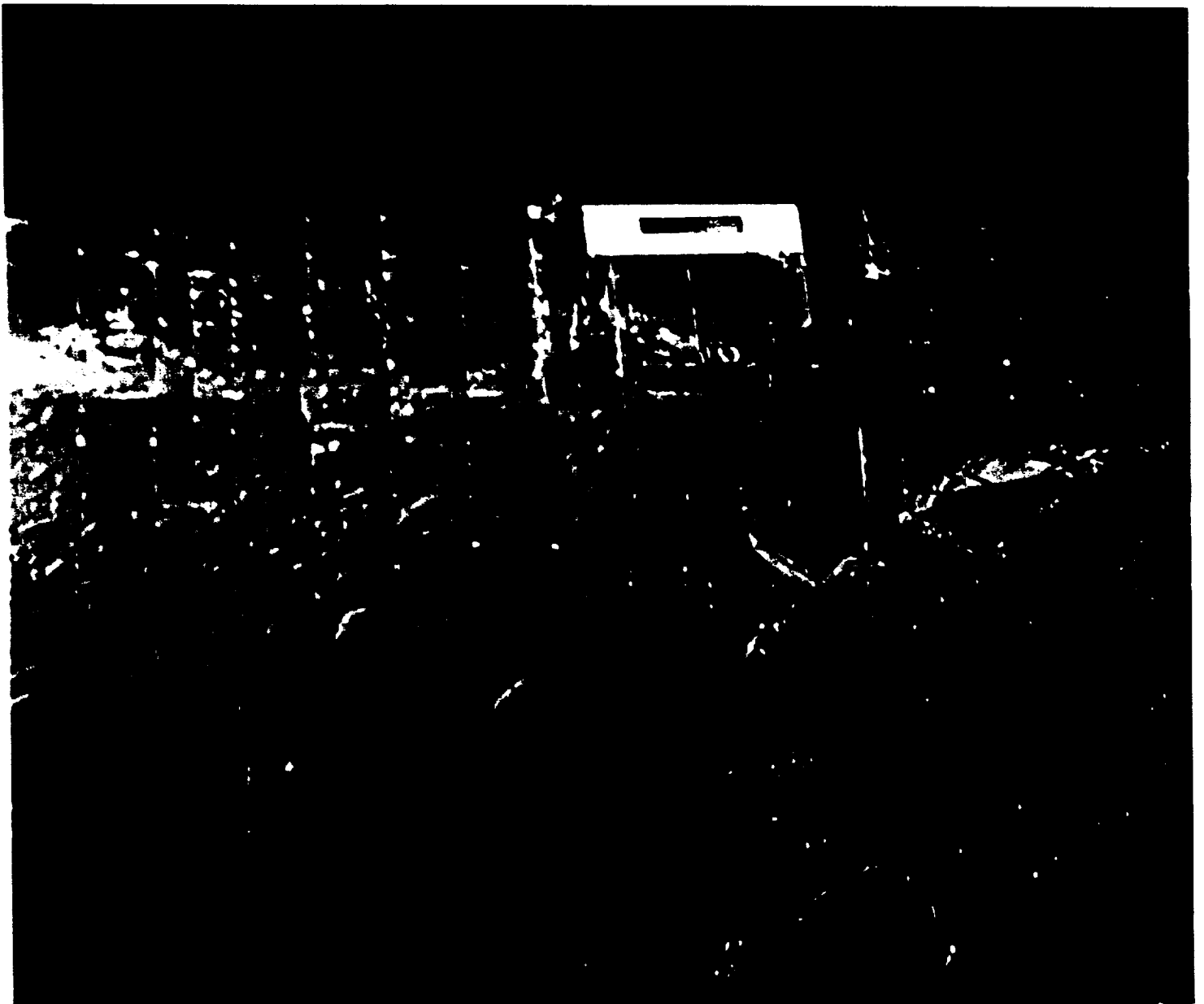
Control of Skylab's Environment

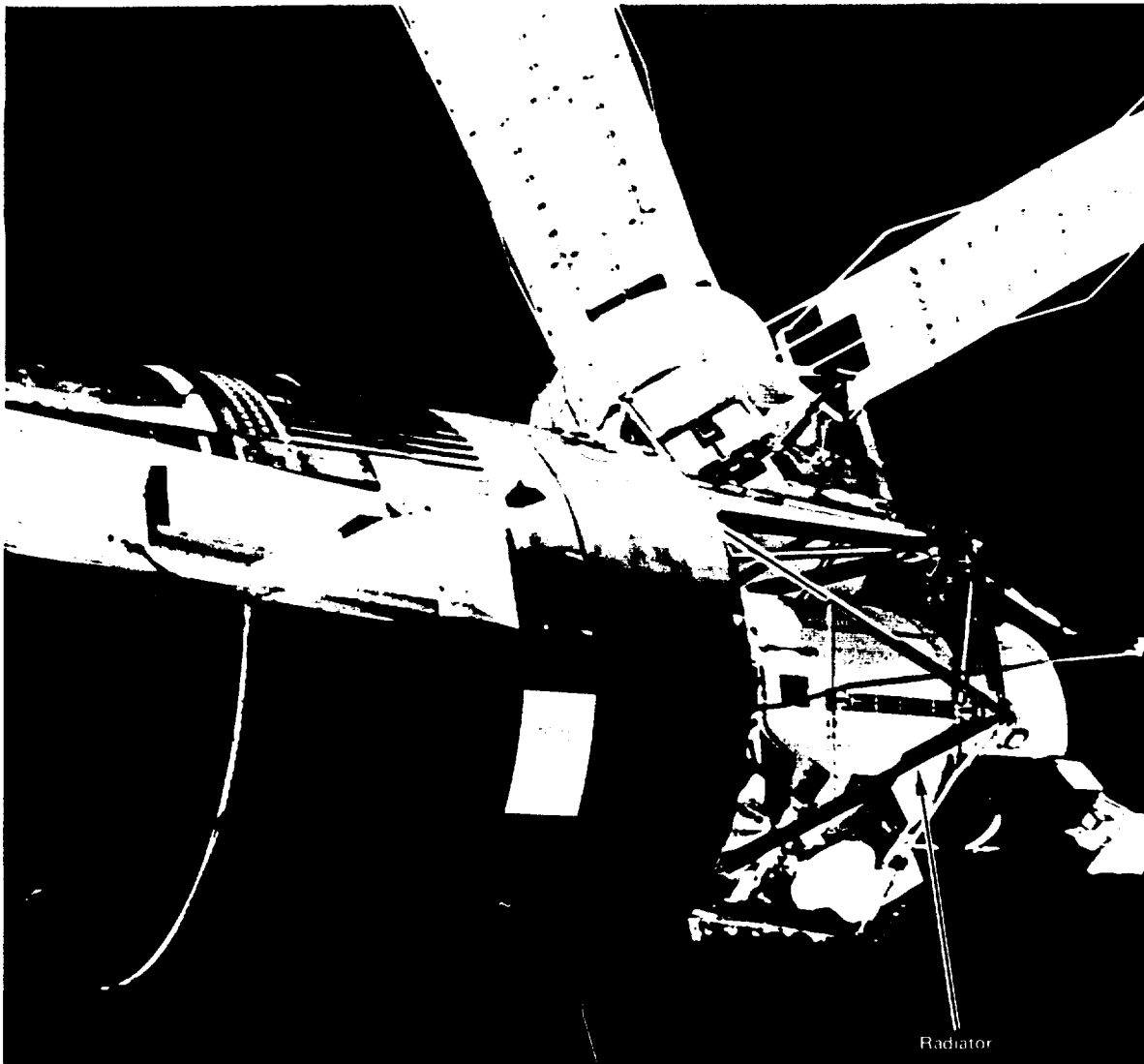
The large volume inside the workshop would result in varying temperatures and the absence of gravity eliminated natural convection. Thus, considerable theoretical work had to be done to establish comfort ranges for the crew. A computerized mathematical model of the human body was developed to investigate comfort ranges.

Skylab's thermal and environmental control

systems were similar in many ways to home-heating and air-conditioning systems. But a number of integrated subsystems were required to make the Skylab a comfortable home in space for the astronauts and to provide temperature control for the many experiments and the space station's equipment. These included not only means for heating and cooling the atmosphere, but also judicious applications of insulation and special surface coatings, as well as provisions for control-

This photograph of the workshop's exterior, filmed during the first crew's flyaround inspection, clearly shows the discoloration and blistering suffered by the workshop skin from prolonged exposure to the Sun. The rectangular opening at the upper center is the scientific airlock, through which the parasol was later deployed.





To cool Skylab and its systems, it was necessary to radiate heat to space. Panels were attached to the cylindrical portion of the airlock and docking adapter. Tubes, through which liquid coolant was circulated, were welded to the interior side of the skin. These radiating devices were effective.

ling the atmospheric gas mixture and constituents, such as carbon dioxide and water vapor.

The primary Skylab coolant system, located in its airlock module, removed heat and moisture from the air. It provided a comfortable environment for the crew and also provided cooling for electrical equipment. In addition, it provided low temperatures for two other cooling systems. One chilled the solar observatory control console in the docking adapter and the electrical components used for the Earth observation experiments. The other brought down the temperatures in the

spacesuits worn by the crew during their work outside the Skylab.

Food and certain biomedical specimens required refrigeration in the workshop, and a cooling circuit was provided which utilized a radiator at the workshop's aft end. Another cooling circuit in the solar observatory maintained the temperature of critical components within required limits.

Heat generated by Skylab equipment and the crew themselves was removed by a combination of systems.

An atmosphere temperature control system



A large octagonal radiator on the aft end of the workshop also radiated heat to space.

picked up excess heat from the compartments and transferred it through heat exchangers into the primary Skylab coolant system where it was radiated to space through a radiator on the cylindrical forward portion of the airlock and the docking adapter.

An onboard thermostat operated four heat-exchanger fans and duct-heater elements to provide conditioned air inside the workshop. Another four duct-heater elements could be turned on manually if sufficient electrical power was available. Eight radiant wall heaters heated the workshop before

the astronauts entered it and also were intended to maintain the workshop above 40°F during the unmanned phase of the mission. The loss of the micrometeoroid shield made these unnecessary, however. Thermostatically controlled heaters were also provided for other walls, docking ports, tunnels, water tanks, overboard vents, and windows to maintain the temperatures within the required limits.

Heat leakage through the structure was controlled by careful selection of coatings and insulations. In the solar environment, coatings with a low ratio of absorptivity to emissivity (white coatings) provide a cold surface; coatings with a high ratio of absorptivity to emissivity (gold coatings) provide a hot surface.

During the first 10 days of the mission, low temperatures developed in some locations within the airlock due to maneuvers necessary to reduce peak temperatures and provide adequate electrical power.

Skylab's design included special coatings and insulations, carefully located on the assumption that the vehicle would be in an attitude in which the solar panels faced the Sun most of the time. When this attitude was changed for long periods to reduce solar heating in the workshop, temperatures in the spacesuit cooling water loops decreased until the water was very close to freezing. Frozen water could have broken lines but, even more serious, water freezing in the heat exchangers would have caused failure of the primary coolant system. This system was vital to the cooling of electrical equipment and to providing a comfortable environment for the crew.

This potentially serious problem further complicated the maneuvering of the space station. After trying many space station attitudes, ground controllers found one which provided the most energy from the Sun without further increasing workshop temperatures. Temperatures in the system which provided spacesuit cooling did remain dangerously close to freezing for several days, but then began climbing slowly.

Skylab's planned 9-month flight posed a unique problem. While the space station orbited the Earth, the Earth's axis tilted as the seasons changed. The net result was that the orbital angle with respect to the Sun (called the beta angle) changed from 0 to ± 73.5 degrees. The corresponding change in the length of time that the space station would be in

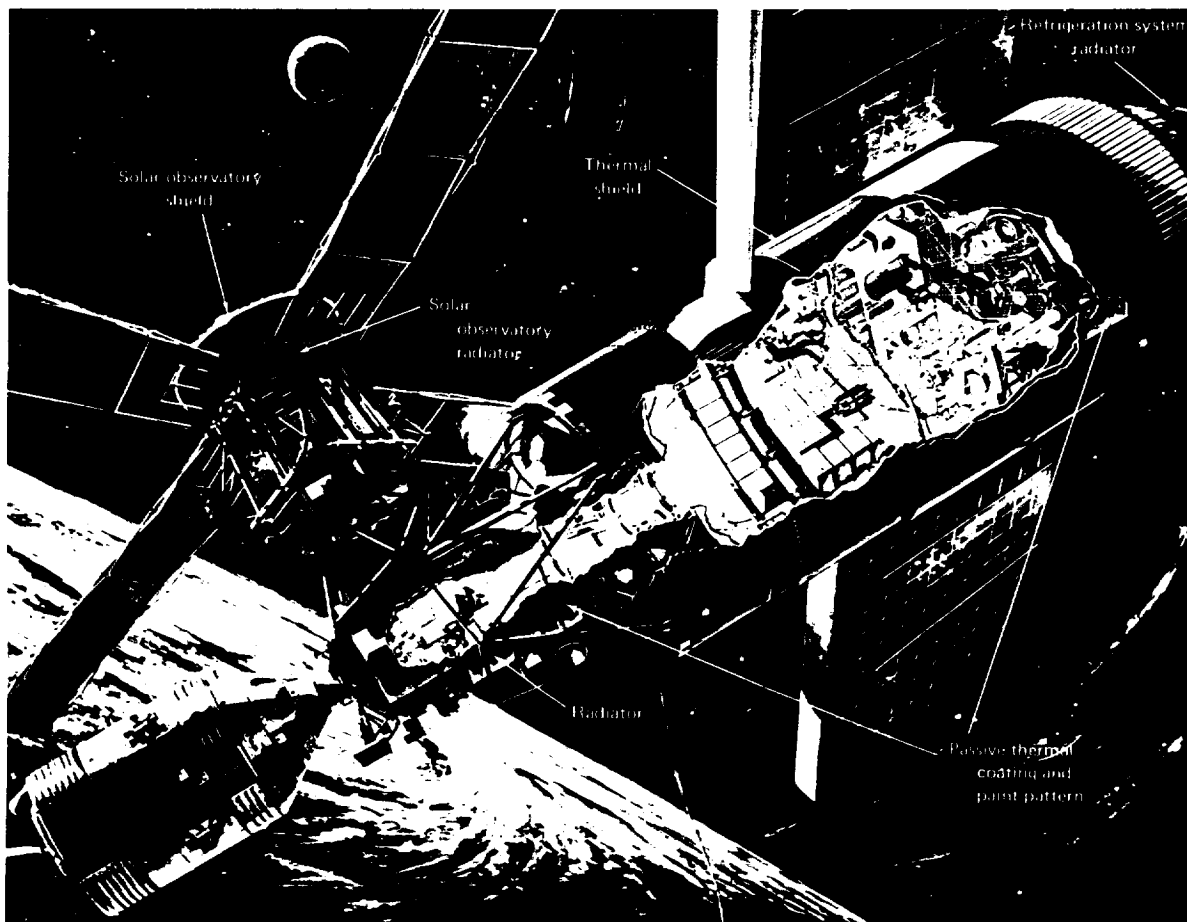
the Sun each orbit varied from 61.5 to 100 percent of the time. Thus, Skylab had to be designed to a much wider variation in the external environment than previous Earth-orbiting manned spacecraft. Also, it had to be designed to fly predominantly in a solar inertial attitude so that one side of the spacecraft faced the Sun for solar observations and to acquire power from its solar wings. Short excursions of one to two orbits were planned for the Earth observation experiments where the other side of the space station faced the Earth, and special maneuvers were planned to view stars and obtain other scientific information and, subsequently, to view the Comet Kohoutek.

Two separate and redundant coolant loops were

provided through most components with the control valves, pumps, and some heat exchangers duplicated in each loop. Normally, one pump was running in each loop; however, all cooling functions could be provided by operating two pumps in either of the loops. The coolant fluid, the pumps, and many of the other components were the same as those used in the Gemini program.

Prior to launch, excess heat was rejected through a ground heat exchanger. Once in orbit the coolant loop rejected its heat to space through a radiator. Two thermal capacitors at the outlet of the radiator provided additional peak capability. These were aluminum-honeycomb boxes filled with a wax which melted at 22°F. They were penetrated

Thermal control system



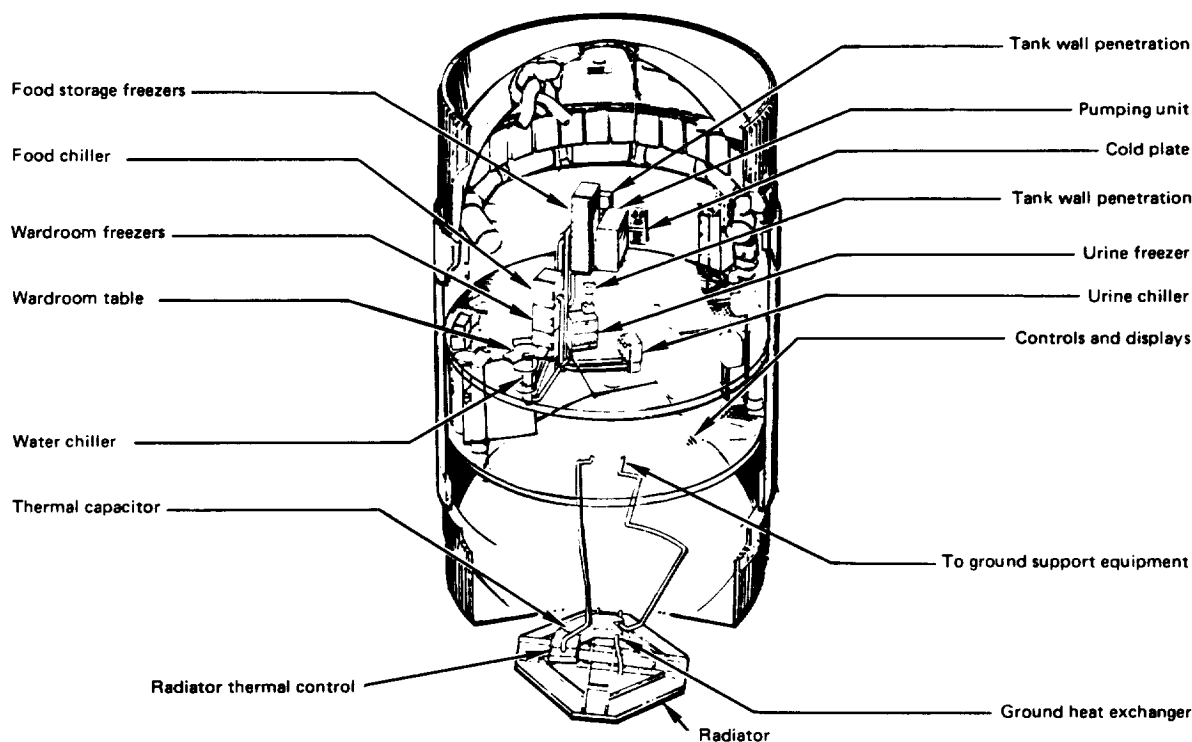
by coolant passages which transferred the heat from the coolant to the wax, and vice versa. Since the radiator was subjected to variable thermal conditions throughout each orbit, a larger radiator than that provided would have been required to assure an acceptable outlet temperature at all times. When the radiator outlet temperature rose above 22°F, some or all of the wax melted and the coolant at the outlet of the capacitor could be maintained at approximately the desired temperature. During orbital operation, the capacitors were to be normally solid on the night side of the orbit and partially molten on the day side, depending upon how much the radiator outlet exceeded the melting point of the wax.

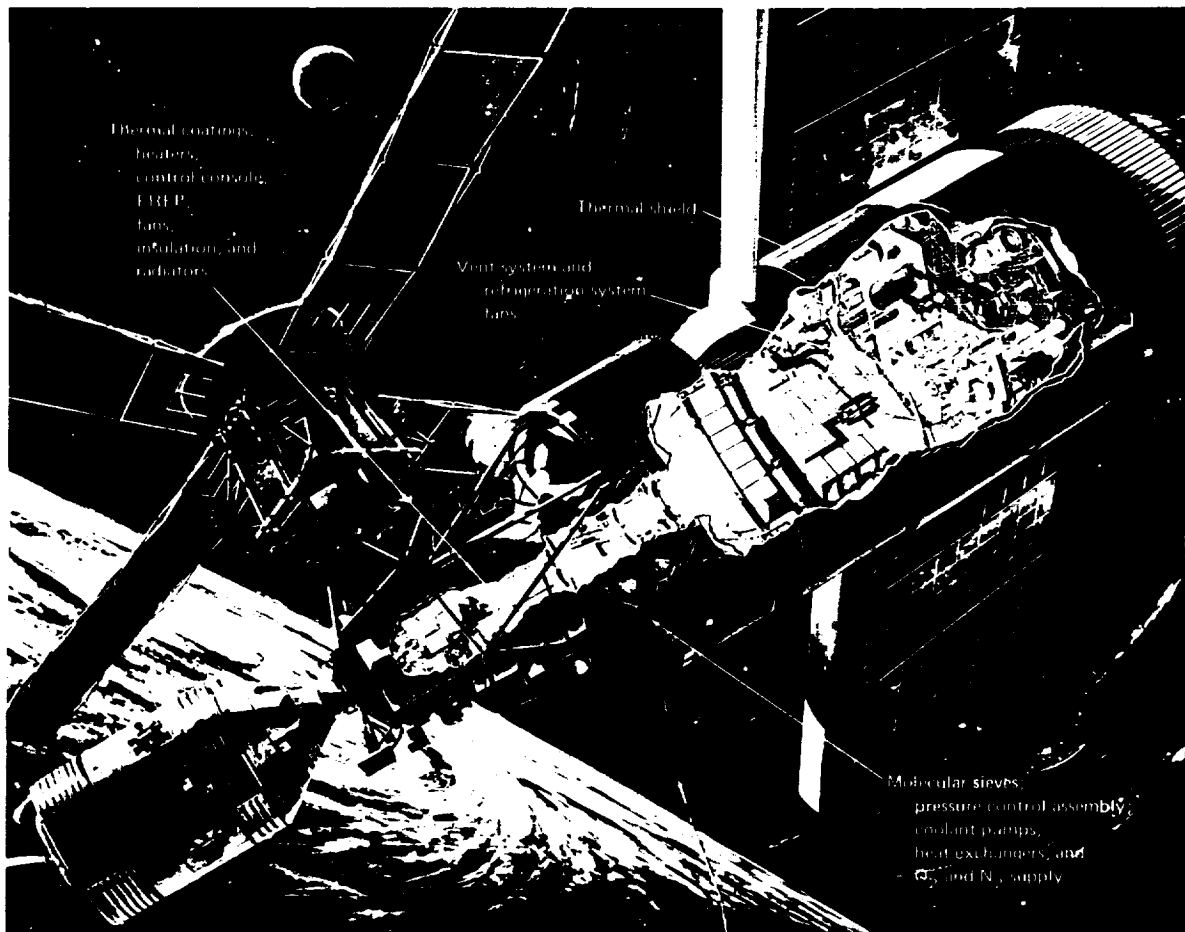
The workshop refrigeration system cooled perishable food and biomedical samples and chilled the drinking water. The workshop was equipped with five food freezer compartments, a food and water chiller, and a urine chiller and freezer. Two independent coolant loops, using a common

ground heat exchanger and thermal capacitor unit, were provided. An octagonal radiator at the aft end of the workshop dissipated heat from this system in orbit. A thermal capacitor similar to that used in the primary Skylab cooling system provided cooling during ascent. Temperatures were automatically controlled by a radiator bypass valve, and other controls were provided which could switch from one pump to another or from one loop to another should temperatures or pressures in the system indicate the need to do so.

The ventilation and atmosphere control systems provided adequate flow for crew comfort, maintained carbon dioxide levels below 5.5 mm Hg for normal operations, maintained the dewpoint between 46°F and 60°F, and removed objectionable odors. Molecular sieves removed carbon dioxide, odors, and moisture. Each sieve unit contained two beds filled with material which absorbed water vapor and carbon dioxide. Every 15 minutes an automatic controller switched the atmosphere flow

Refrigeration system





Environmental control system

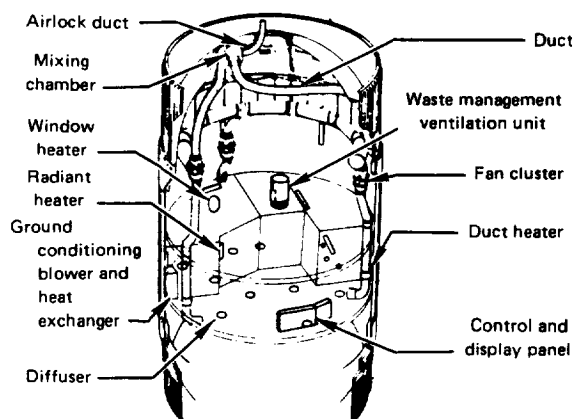
over to a fresh bed and vented the saturated bed to space. The concept did not require replacement of filter elements, a feature of early short-duration manned space missions.

Since there was no gravitational force to drain the condensate from the heat exchangers, this function was accomplished by a suction line connected to a tank whose pressure bellows had been evacuated by venting to space. Once the tank filled with water, valves were manually switched so that the bellows could be pressurized by the cabin atmosphere. This forced the water into the waste tank at the aft end of the workshop.

Charcoal canisters in the molecular sieves and a charcoal canister in the waste management com-

partment ventilation unit of the workshop removed odors from Skylab. A fan filter in the waste management compartment removed particulate matter, such as hair and lint, from the workshop atmosphere.

Purified air from the molecular sieves could be diverted to either the workshop or the multiple docking adapter compartments or divided between the two, as desired. Ambient atmosphere in the structural transition section of the airlock module was mixed with this revitalized atmosphere and combined with the outlet flow from the four workshop heat exchangers before dissemination. A flexible duct was connected to a mixing chamber at the forward end of the workshop where the flow



Ventilation system

was mixed with a portion of the workshop atmosphere. The flow was then channeled into three ventilation ducts. Four fans in each of these ducts routed the atmosphere to a large distribution chamber at the aft end of the workshop. The crew quarters floor was equipped with adjustable diffusers which circulated the air through the crew quarters and back to the forward end of the workshop. A portion of the atmosphere flowed through the hatch and the airlock tunnel, returning to the molecular sieves for reconstitution. The remainder was drawn into the mixing chamber and recirculated in the workshop.

Thermal Control of the Solar Observatory

The solar observatory was exposed to the Sun throughout most of the Skylab mission. To maintain optical stability of its instruments, the temperature of its components required careful control.

An octagonal structure, known as the rack, supported the experiment canister. It also served as a mounting structure for more than 140 electrical and mechanical components designed for operating temperature ranges from -4.6°F to 121.4°F . Additionally, all hardware used or touched by astronauts during spacewalks had to be maintained at acceptable temperatures. This was accomplished by several methods. Surfaces were painted white to reduce solar heating. Thermal shields protected sensitive components with low internal heating from cold environments; these shields were covered with varying thicknesses of multilayer insulation to control heat losses. All major mounting panels,

except those containing high-heat dissipating components such as batteries, were isolated from the rack structure and covered with multilayer insulation on the canister side. Components were located so that power distribution in major zones around the rack sides was reasonably uniform. Components dissipating heat at high rates were mounted on external panels. Finally, a rack-mounted Sun shield prevented continuous direct solar impingement on rack components.

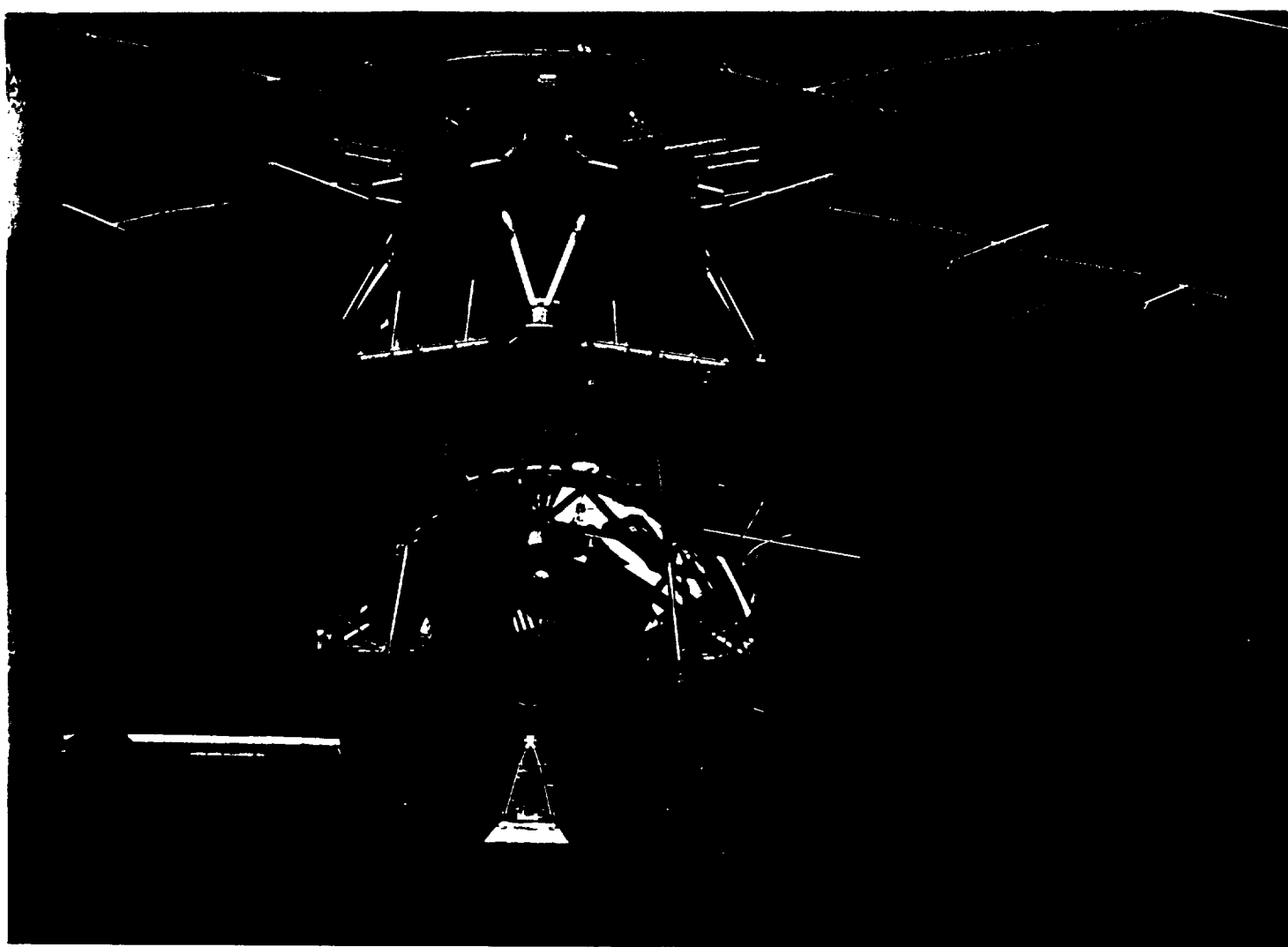
The canister, an insulated cylinder shielding the eight telescopes, provided a uniform and nearly constant internal environment and served as a stable platform. All instruments were mounted on a cruciform-shaped spar, an isolated structure that divided the canister interior into four longitudinal compartments. The spar was supported by a girth ring that connected to a gimbal system. Spar thermal isolation minimized spar temperature changes and prevented optical misalignment. Thermal isolation was achieved by using low-conductance mounts where the instruments attached to the spar and where the spar attached to the girth ring. In addition, the aluminum spar was covered with multilayer insulation. The canister exterior was covered by a multilayer insulation to protect its cold plates. This insulation, originally developed for the Apollo program, is used in making rescue blankets.

The canister's interior walls, painted black to minimize reflections and maximize radiative coupling between instruments and liquid-cooled "cold plates," were maintained at a nearly constant temperature by a closed-loop fluid, heat-transfer system. Heat generated by the instruments was absorbed by the cold plates, transferred to the radiator by a fluid, and then radiated to space.

Separate thermal design of each telescope was required to satisfy individual pointing stability requirements and maintain focal lengths within specified tolerances.

First Visit to the Workshop

When Conrad, Weitz, and Kerwin awoke, their most pressing activity was to make sure that the atmosphere inside the workshop was suitable for occupancy. Engineers at the various NASA centers had taken special precautions to assure that the heating to which the insulation had been exposed did not cause a gaseous residue in the workshop.



The solar observatory was designed for full exposure to the Sun throughout most of the Skylab mission. The temperature of its components was carefully controlled.

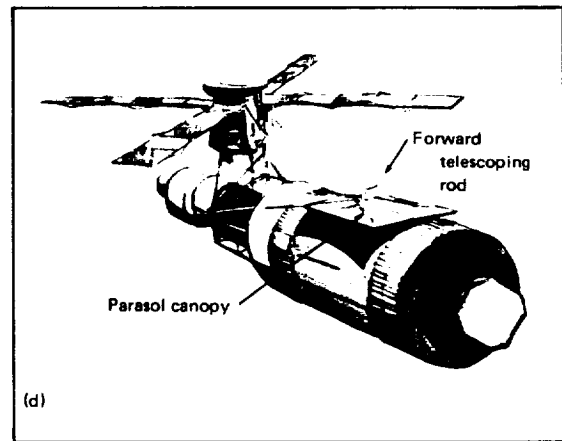
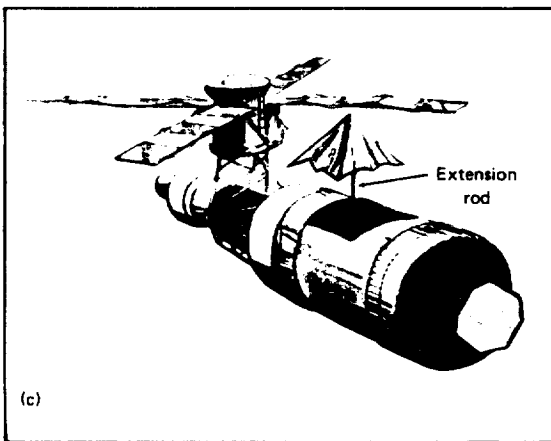
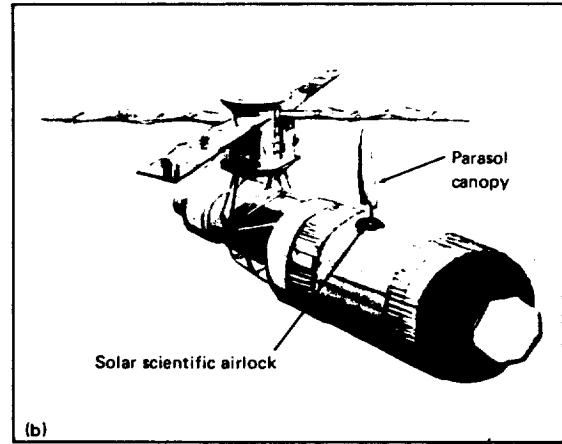
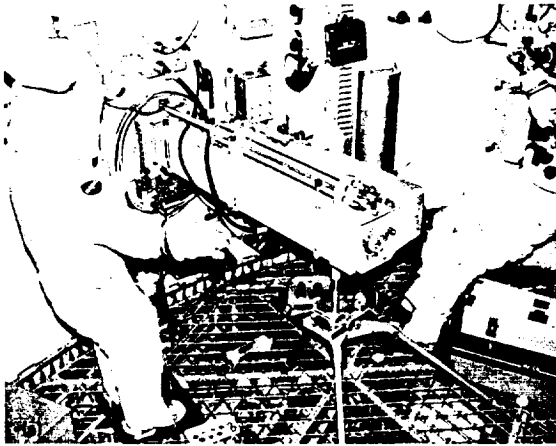
Maneuvering of the spacecraft had held temperatures to a level which prevented decomposition of the insulation. The pressurization and depressurization cycle, which had been carried out for several days, had effectively removed any undesirable atmospheric elements which might have been present.

As Weitz donned a gas mask and began sampling the atmosphere, he found no evidence of noxious or toxic gases. Satisfied that the atmosphere was safe for occupancy, Weitz and Kerwin entered the workshop and began its activation. The temperature inside was 130°F, but the humidity was so low that they could work inside for as long as 5 hours.

Using procedures worked out carefully in engineering laboratories, the crew erected the parasol thermal shield.

First, they attached the canister to the scientific airlock. Then Conrad and Weitz, working cautiously to be sure that they did not force structural members out of shape, extended the folded shield through the opening and into space. Slowly, the struts extended and the sunshade took shape. Although one corner did not extend fully, the trapezoidal-shaped shield was in place over the workshop outer surface. Almost immediately, temperatures inside the workshop began to drop.

With the parasol shield deployed, Conrad and his crew continued workshop activation. Temperatures



Sequence of parasol deployment. (a) Parasol operation from interior of airlock. (b) Parasol at partial extension. (c)

Full extension and partial deployment. (d) Fully deployed and retracted for service.

of the outer wall decreased rapidly, and about an hour later, ground controllers returned the Skylab to the solar inertial attitude. The result was an immediate increase in electrical power as the full force of the Sun's rays fell on the solar observatory solar array.

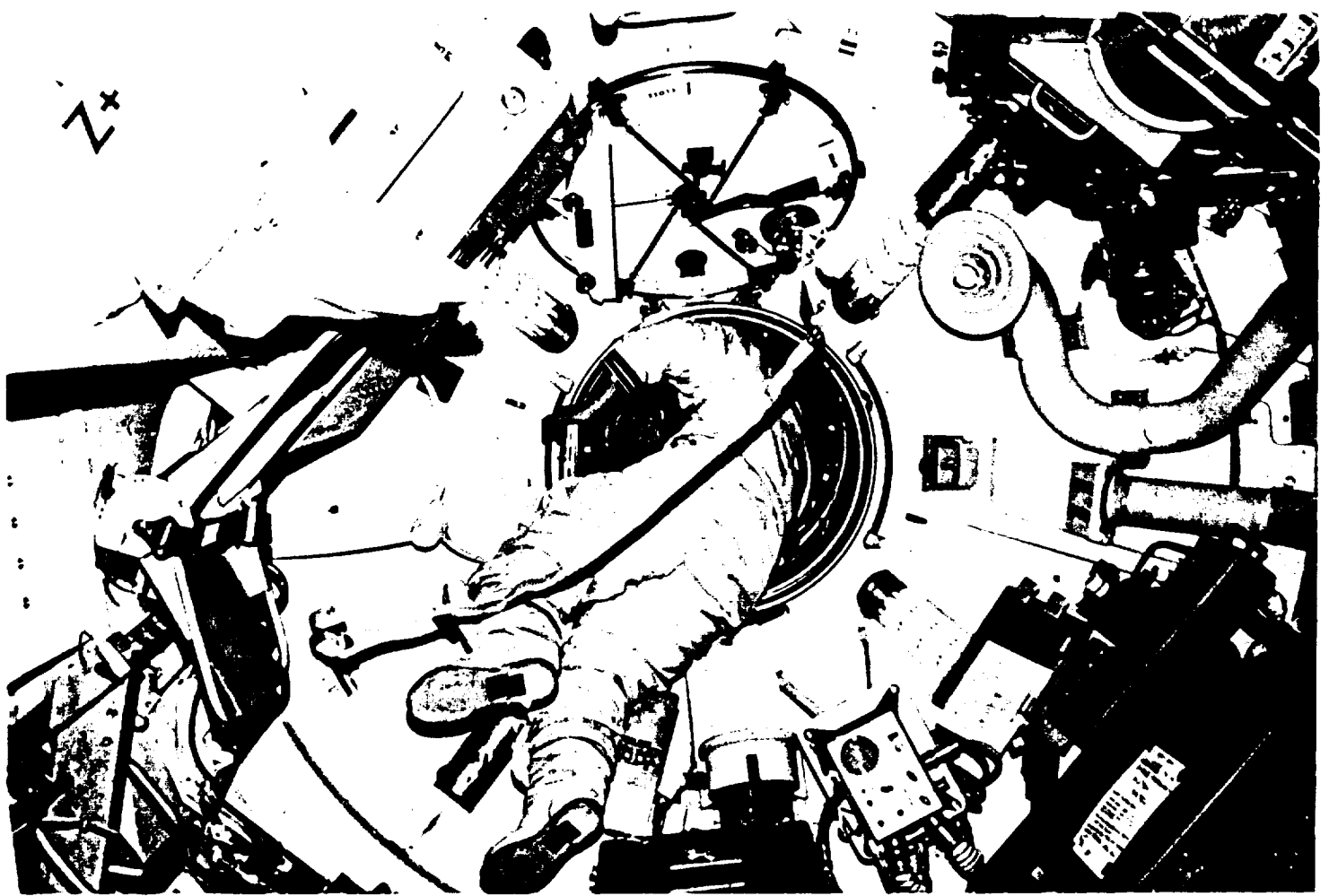
Even though most of their activities had been of an emergency nature, and temperatures inside the workshop were still high, the crew adjusted quickly to their new environment.

Temperatures inside the workshop dropped to about 90°F, but for the first few nights the crew slept inside the docking adapter, where the temperatures were a comfortable 68°F.

A Sense of Up and Down

"You do have a sense of up and down," Scientist Pilot Kerwin reported. "And you can change it in two seconds whenever it's convenient. If you go from one module into the other and you're upside down, you just say to your brain, 'Brain, I want that way to be up.' And your brain says, 'Okay, then that way is up.' And if you want to rotate 90 degrees and work that way, your brain will follow you. I don't think it's vestibular at all. I think it's strictly eyeballs and brain. And it's remarkably efficient."

The crew quickly established a normal routine



Orientation in the space station was never a problem. As the crew adjusted to its new environment, Scientist Pilot Joe Kerwin reported that there was, indeed, an up and down in space. It was simply a matter of telling yourself

which was which, he observed. In this photo taken by Astronaut Weitz on the final day of the mission, Kerwin is shown in the hatch between the Multiple Docking Adapter and the Apollo spacecraft.

of carrying out experiments, housekeeping, eating, sleeping, and exercising. A careful schedule, worked out between flight and ground crews, was maintained to assure the proper performance of routine maintenance tasks and experimentation. The crew's typical day consisted of 16 hours of activities and 8 hours of sleep. All crewmen slept at the same time.

In scheduling their activities, the crew had to allocate time for observations of the Earth and the Sun, taking into account Skylab's orbital position. After these observation periods were scheduled, other activities could be accommodated.

Since virtually all electrical power came from the solar observatory power system, the experiment program was stretched out, but it was still carried out almost as planned. Six experiments could not be performed as planned, since they had

been designed to make use of the Sun-facing scientific airlock, now occupied by the parasol. But the flight crew modified the program and conducted three of the experiments using the scientific airlock in the Earth-facing side of the workshop. Two of the remaining three experiments were mounted on the solar observatory truss and the other on the solar observatory Sun shield by the crew during extravehicular activity.

Even without power from the workshop solar array, there was an average of about 800 to 1000 watts available for experiment purposes over that needed to maintain essential functions in Skylab. But the solar observatory batteries were being overworked. To fulfill all mission objectives, the workshop solar array would have to be deployed.

As the flight crew continued its work in space, ground teams worked around the clock to develop



Kerwin extended the long-handled cable cutter while Conrad affixed the cutter jaws to the strap holding the solar wing. Together, they cut the strap, which freed the wing, and then they extended it to its full position.

procedures for freeing the workshop solar-array wing. The flyaround television pictures of the restrained beam fairing underwent continuous study. Tests continued in the neutral buoyancy simulator, where Astronaut Russell "Rusty" Schweickart used tools and equipment identical to those on board Skylab to practice procedures for freeing the jammed beam. The simulated solar-wing beam structure in the tank was fitted with debris resembling the actual situation on the Earth-orbiting space station as shown on the photographs relayed from space.

Along with fellow Astronaut Edward Gibson, who would be the scientist pilot of the third crew, Schweickart tried cutting the aluminum strap holding the wing in place, using the pry bar, a bone saw, and the cable cutter. Each method was successful. Deploying a pole from the hatch of the airlock module, and using the cable cutter on the outboard end as a clamp, one astronaut used the pole as a handrail to maneuver the solar-array panel. This new procedure was described in detail to Conrad and his crew aboard Skylab.

On June 7, Conrad and Kerwin opened the hatch on the airlock module and moved out on the airlock shroud to assemble their tools and equip-

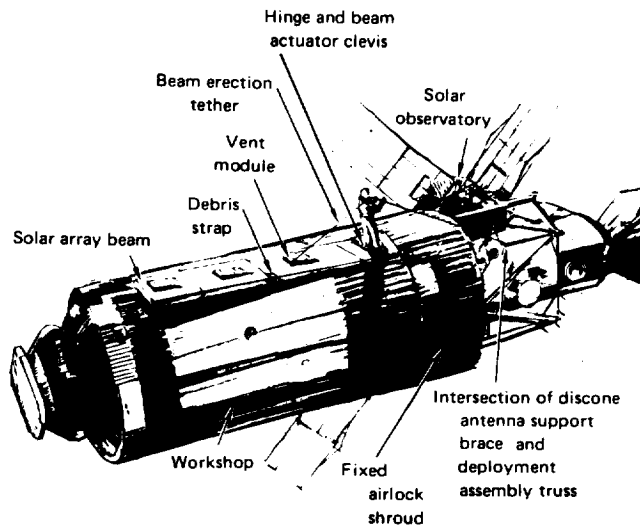
ment. Weitz remained inside. Schweickart, with his simulator experience, talked to the crew from Mission Control at Houston. Engineers at Houston and Huntsville listened intently to the operation, ready to give advice if needed.

Standing outside the workshop, Conrad and Kerwin assembled the 25-foot-long aluminum pole from its five sections. They then attached a cable cutter tool to one end and carefully maneuvered the pole until the cutter jaws were clamped on the debris on the solar-wing beam. While Schweickart relayed instructions, they fastened the other end of the pole to the solar observatory truss structure.

Attached to a tether, Conrad worked his way hand over hand to the wing beam. Once at the beam, he determined that the cutter jaws were correctly positioned on the debris.

Now, orbital night stopped them, but as the

Extension of the solar wing became a problem, even after the offending strap had been cut. With one end of a rope attached to the vent module on the wing and the other to the deployment assembly truss, Conrad stood up stretching the rope over his shoulder. This provided sufficient leverage to deploy the wing.



spacecraft moved back into daylight, they were ready once more.

Kerwin pulled hard on the lanyard, which operated the cutter jaws. "Man, am I pulling," he exclaimed.

Nothing happened.

He pulled even harder. Since the cutter jaws appeared to be spreading without cutting the strap, Conrad made his way back along the beam to examine the cutter jaws.

As he reached the scissors-type mechanism, the cutter severed the strap, and the beam, now free, moved suddenly. The unexpected action propelled Conrad tumbling into space, where the tether restrained him. The excitement caused him to miss seeing what happened as the wing deployed some 20 degrees.

Now the problem facing Conrad and Kerwin was to deploy the beam the full 90 degrees so that the solar arrays could be extended. This problem had been anticipated, and procedures for deploying the beam had been carefully worked out on the ground and tested. Before cutting the metal strap restraining the beam, Conrad had hooked a tether to a vent module relief hole on the beam. The other end of the tether was firmly secured to an antenna support truss on the solar observatory.

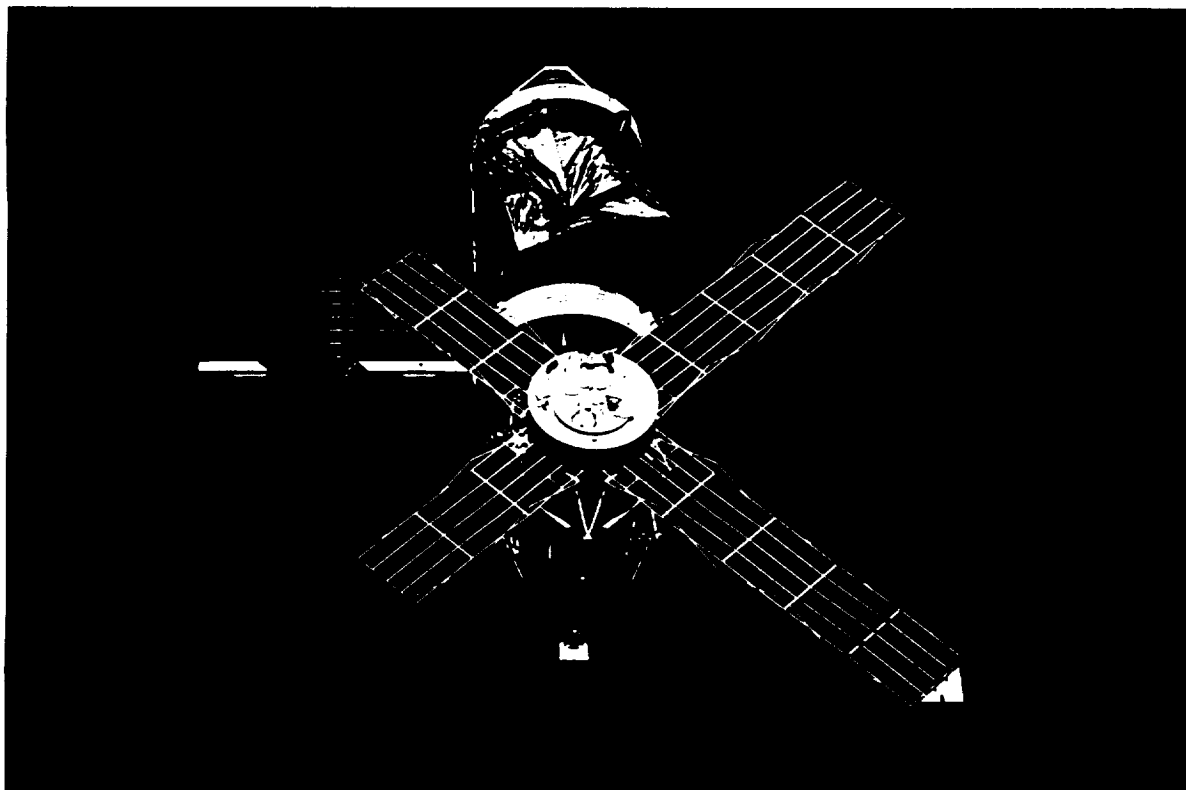
Both Conrad and Kerwin tugged on the tether to move the beam, but without success. Conrad then worked himself along the beam to where it hinged to the workshop. Standing at the hinge, he lifted the tether to his shoulder and stood erect, while Kerwin pulled on the tether again.

Suddenly, the clevis bracket on the actuator broke, freeing the beam. As Conrad and Kerwin again tumbled into space, restrained by their tethers, the beam swung out to its fully deployed position.

As the two astronauts began disassembling the tools and stowing their gear, the Sun's rays warmed the deployment mechanism. Slowly, the three panel sections began extending. Now, ground controllers maneuvered Skylab to allow solar heating of the fluid in the wing section actuator-dampers. Within 6 hours after the beam was freed, the individual wing sections were fully deployed and functioning. This increased the power capability from 4000 to 7000 watts, thus assuring that Skylab would be able to carry out its mission completely.

Conrad, Kerwin, and Weitz had kept their word. They had demonstrated that, properly trained and equipped, man could carry out difficult repairs in space.

Shading of the workshop and deploying the solar wing made Skylab fully operable. The addition of the workshop solar array provided much-needed electrical power and the parasol shielded the workshop from high temperatures.





5

The First Manned Period

Before Conrad and Kerwin completed freeing the workshop solar wing, trouble developed in the systems which cooled the spacesuits and the workshop.

Problems in Suit-Cooling Loop

While performing spacewalks, astronauts wore undergarments which were cooled by water from either of two supply loops. The water in each loop was cooled in a heat exchanger, which transferred the water's heat to a coolant flowing through the workshop's primary cooling system. Each of the loops had two pumps, a reservoir containing the water supply, and a separator whose function it was to remove gas from the circulating water.

Conrad and Kerwin were outside the spacecraft for 3½ hours trying to free the solar wing. Each wore a spacesuit connected to a separate cooling loop. Before going outside, they had turned on valves in the primary coolant system. This action also activated heat exchangers to provide additional suit cooling. Apparently, this action caused solid particles to be flushed out of the heat exchangers and lodge in the temperature control valves, causing valves to stick. Temperatures in Conrad's suit loop decreased rapidly, and water apparently froze in the heat exchanger since water flow through his suit stopped completely.

At the time, the full extent of the problem was not realized since the secondary coolant loop appeared to be functioning adequately, and it was

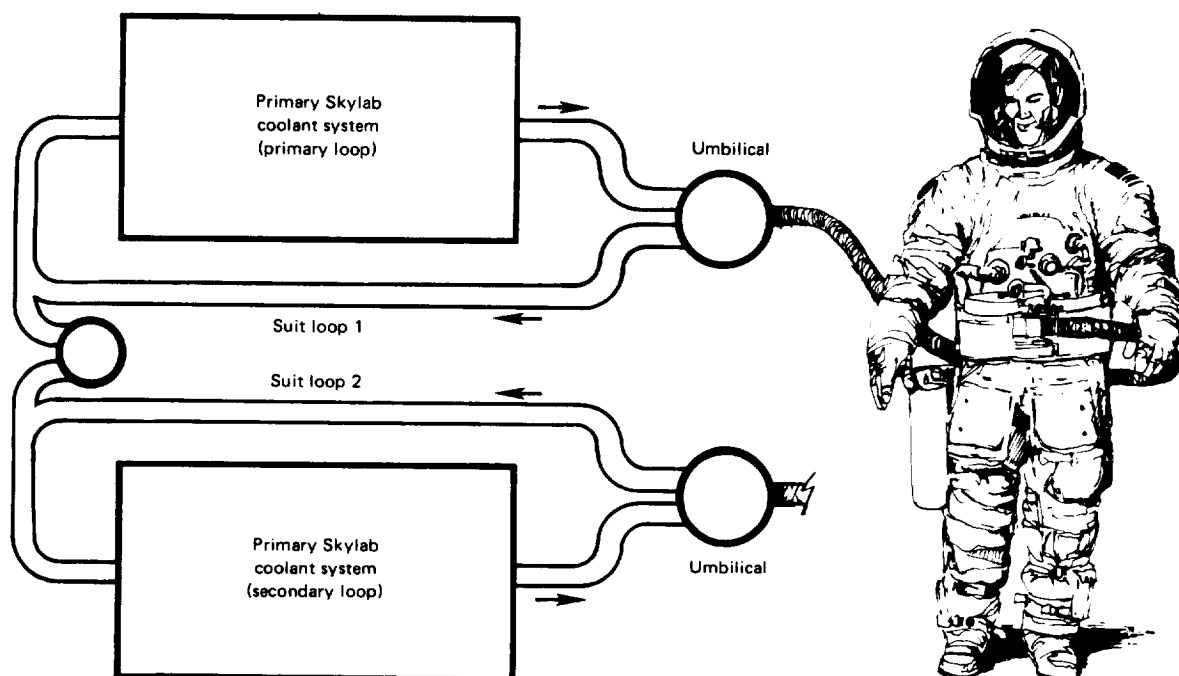
sufficient to provide adequate cooling. Conrad and Kerwin went on to complete the freeing of the solar wing. Once they were back inside the airlock, as they were disconnecting the second suit loop, they discovered that the valve in the secondary coolant loop was also stuck. They turned off the secondary coolant loop and tried the primary loop again. Temperatures dropped still lower. On the advice of the ground engineers, they switched back to the secondary coolant loop, which was still maintaining temperatures at a more acceptable level.

After the crew had gone to sleep, however, temperatures continued to drop in the secondary loop. Ground controllers woke the crew, and instructed them to connect the two liquid-cooled garments to the coolant system and to place the garments against a water storage tank which was relatively hot because it was on the Sun side of the workshop. This action added heat from the tank to the water in the loop. Temperatures rose to 40°F and stabilized there.

The crew went back to sleep, but the mission was still in jeopardy.

One of the loops in the primary coolant system was inoperative. Failure of the other loop, already operating erratically, would result in intolerably high workshop temperatures and overheating of electrical components.

The valves which controlled flow through these loops were located outside the airlock module. The only means of freeing them was through thermal



Diagrams showing the two loops through which water circulated to cool the astronauts during their extravehicular activities. Circulating water flowed through "long underwear" worn under their pressurized suits. Heat was transferred to the primary workshop cooling system through intermediate heat exchangers.

cycling, which would cause the internal valve bellows to expand and contract. This action would move the valve first in one direction and then the other and dislodge any particles causing the valve to bind.

A time was selected for performing the operation when Skylab was in continuous contact with a ground tracking station. The plan was to turn on a pump in the primary loop while the crew and ground controllers carefully watched system performance. If the procedure was not successful, the pump would be turned off before damage could occur to the system.

The first attempt was unsuccessful, and the loop was shut down. Twelve hours later, the procedure was tried again. This time, temperatures stabilized at 47°F. The primary loop was now fully operational. Using the same procedure, the valve in the secondary loop was also freed.

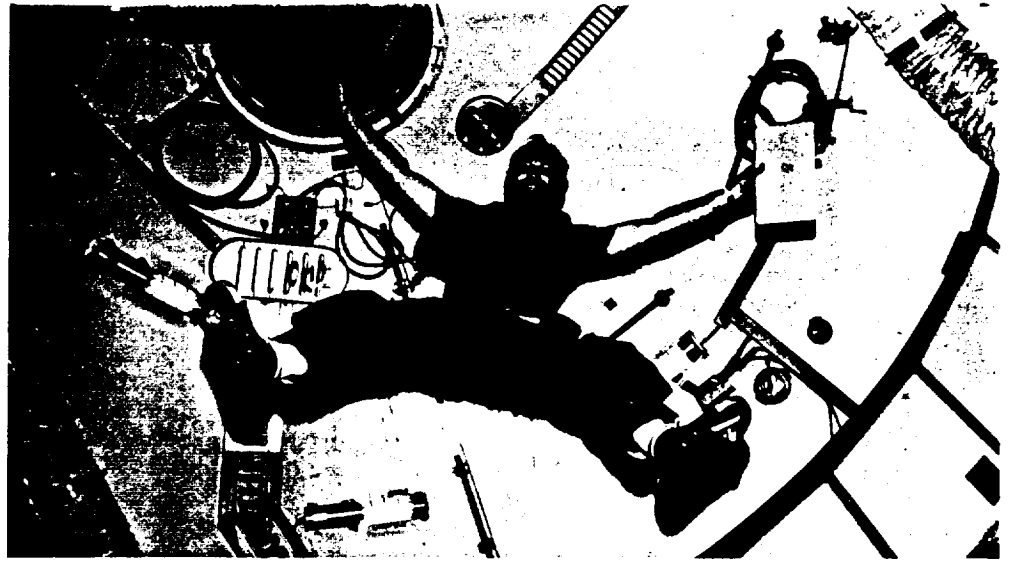
A Home in Space

By this time, Conrad, Kerwin, and Weitz were seasoned space travelers. They had adjusted well to their new environment. The long hours spent in simulators and other exhaustive training had paid off handsomely.

"Mobility around here is super," Conrad reported. "Nobody has any motion sickness. Every kid in the United States would have a blast up here."

The cavernous workshop, 27 feet long and 22 feet in diameter, invited exploration. In the weightlessness of space, they soared around their home, embellishing their flights with flips, cartwheels, and inventive gymnastic exercises.

Skylab designers had provided recreational equipment to vary the routine of long hours in space. There were dart sets (without sharp points),



The weightlessness of space transformed Skylab's crewmen into skilled acrobats. They found that, within the roomy workshop, and without the impediment of gravity's pull, they could perform feats that even the most talented acrobats on Earth could not duplicate.

playing cards, balls, books, exercise equipment, and a tape player. But much of this went unused. Earthgazing during orbital daylight and star watching during orbital night became principal diversions.

Conrad reported: "I've spent a lot of time in space before at 150 nautical miles, but this 237 is just unbelievable. You can really see the curvature of the Earth. As we came over the northern part of the United States east coast, we could see into Canada and clear down to the Keys."

Later, he said: "You can see the whole Bahama chain and all the shallow water and all the deep water in one big picture. It's really fantastic."

Kerwin also had kind words about the functioning of Skylab's toilet.

"We owe our greatest appreciation to the people who designed it," he said. "It has worked much better than anticipated, and it has been essentially trouble free and not terribly time consuming."

The Skylab toilet, designed to function in the weightless environment, bore little resemblance to that found in home bathrooms. It was designed so that crewmen could eliminate body wastes through the necessary acts of urination and defecation. But it also supported biomedical experiments by sampling and preserving certain body wastes and disposing of the remainder. The entire system included a fecal-urine collector, collection and sample bags, sampling equipment, odor control filters, and a fan. The toilet was mounted on the wall rather than the floor of the bathroom, in the crew quarters area.

Defecation in space was complicated by the absence of gravity to move waste material away from the body. On Skylab, a hinged, contoured seat provided access to the mesh liner into which the astronaut inserted a fecal collection bag. Air was drawn through the fecal bag from holes in the seat and exhausted through the bag's vapor port, through the mesh liner, into the fecal collection receptacle, and then through a filter, where odors were removed, before it was recirculated into the cabin by a fan.

To use the toilet for defecation, the crewman sat on the contoured seat, then fastened a belt across his lap to hold himself securely in position. Handholds and foot restraints allowed him to maintain a sufficiently tight seal on the seat, as airflow from the fan separated the fecal matter from his body and deposited it in the fecal

collection bag. A separate fecal bag was used for each defecation.

The crewmen could urinate from either a standing or sitting position. A urine collector, located on the wall just below the fecal collector, also utilized airflow as a substitute for gravity to draw the urine through a receiver and hose into a urine collection bag. An alternate device incorporated a funnellike attachment through which the bag could be filled by bladder pressure.

Feces and vomit were collected in bags and vacuum dried with heat, then stored for return to Earth or dumped into the waste tank. The return of body waste samples was necessary for chemical analysis to determine the effects of spaceflight on musculoskeletal metabolism to measure the daily gains or losses of pertinent biochemical substances. The drying process made the solid biological wastes inactive, a function performed on Earth by sewage-processing plants.

After the urine was collected, air was removed in a liquid-gas separator centrifuge. Then a sample was removed and frozen to prevent chemical changes prior to analysis on Earth. The remainder was disposed of in the waste tank. Urine and blood samples were returned for analysis to evaluate adaptation resulting from extended exposure to the space environment, to space diets, and to Skylab workloads.

The waste management area also included utility closets where supplies for personal hygiene and house cleaning were stored. Tissues, waste collection bags, soap, and utility wipes were among the items stored there. Utility wipes were used both as toilet tissue and for cleaning.

Skylab's zero-gravity shower compartment was collapsible. Located in the experiment and work area of the workshop, it was a cylindrical cloth enclosure that was folded flat when not in use. The bottom ring of the shower was fastened to the floor and contained foot restraints. The upper ring contained the shower head and hose. To use the shower, the astronaut filled a pressurized portable bottle with heated water and attached the bottle to the ceiling. A flexible hose connected the water bottle to a hand-held shower head. The astronaut pulled the cylindrical shower wall up into position and bathed, using liquid soap. Both soap and water were carefully rationed, having been premeasured for economical use.

Astronaut Weitz was the first to test the shower.



This photograph shows the waste management compartment, with the fecal-urine collector mounted on the wall.

He reported that "it took a fair amount longer to use than you might expect, but you come out smelling good."

Each crewman had his own personal hygiene kit, which contained a razor, shaving cream, hand cream, toothpaste, toothbrush, comb, nail clippers, deodorant, and other personal items. When Conrad and his crew opened their kits, they found that the highly elevated workshop temperatures had caused some of the hand cream and toothpaste tubes to rupture but enough remained for their use during the time they occupied the workshop. The shaving cream container was intact, but the cream had hardened; water had to be added before it could be used. The second crew brought replacement kits with them.

Clothing worn by the crewmen was designed for comfort and safety. In all, more than 700 items of clothing were provided for the Skylab crewmen. Among these items were 39 jackets, 69 pairs of trousers, 126 shirts, 30 pairs of boots, 18 pairs of gloves, 4 union suits, 201 T-shirts, 45 half union suits, 85 jockey shorts, 112 boxer shorts, 54 knee shorts, 286 pairs of socks, and 24 constant-wear garments.

The gold-colored shirts, trousers, and jackets were made of a special fire-resistant fabric. The ankle-high boots and wrist-length gloves were lined with a fire-resistant fabric.

Towels and washcloths were provided both for personal hygiene and for general cleaning purposes. They were made of rayon terrycloth, and each was stitched with an identifying color coded for the individual crewman. In all, there were 840 reusable washcloths and 420 towels stowed in dispensers in the waste management compartment. Disposable wipes were also provided. Wet wipes were used principally for food cleanup and housekeeping. Dry utility wipes were used primarily as toilet tissue. Biocide wipes were used for housekeeping activities that required disinfection, such as cleaning up food spills and removing contamination in the fecal-urine system. General-purpose tissues were used for general housekeeping and personal use.

Inside the workshop, airflow was a limited substitute for gravity. Crewmen learned quickly to begin their search for missing items by looking on the surface of the air filters and screens, as loose objects usually found their way there. One screen duct became a favorite workbench, as the crewmen

found that tools and equipment could be held there by airflow against the screen.

As the result of many habitability studies and considerable experimentation, Skylab had been designed so that crewmen and equipment could be held securely in place, when necessary, or could be moved as needed. The walls and ceilings were a metal triangular gridwork. Shoes worn by the astronauts had triangular plates fastened to the soles, which fitted through the triangular opening in the grid. By turning his foot slightly, the astronaut could hold himself as he worked. There were also other means of restraint. One was a set of straps similar to those on shower clogs. Three pairs of these were placed on the floor of the wardroom at the base of the food table, and another pair was located in the waste management compartment. Still another type of foot restraint, for use with spacesuits, consisted of toe bars and heel fittings which could be fastened to floors or walls.

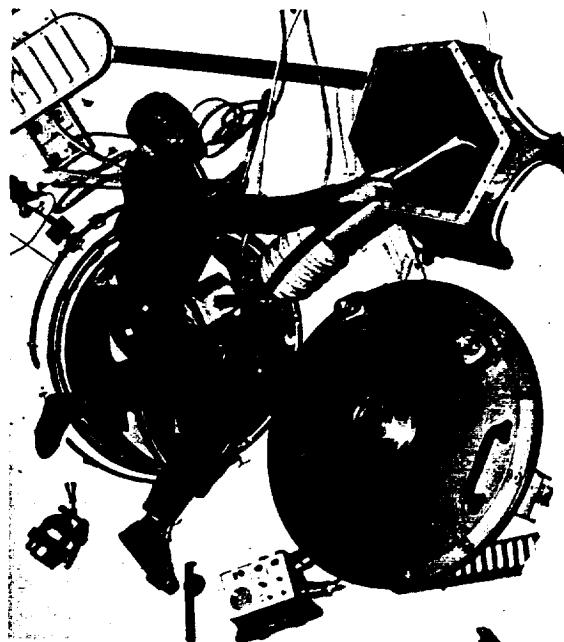
Straps of varying lengths and elastic cords were stored on Skylab for holding objects securely in place. Rubber cups with a cross cut in the end were used to hold washcloths and towels. Adjustable universal mounts were provided for items such as cameras. These could be moved wherever they were needed and snapped into place. Throughout Skylab, there were provisions made to hold such temporary restraints as clips and snaps.

Handrails and handholds, colored blue for quick identification, were located throughout Skylab. A removable, collapsible "fireman's pole" extending from the workshop hatch to the floor of the forward compartment provided a means of rapid movement. However, the astronauts soon found that they could move about easily without using it, and it was removed and stowed.

Thigh restraints consisted of a round bar, with two crossbars. In use, the astronaut straddled the main bar with his legs between the crossbars. Such restraints were provided at the food table, but the astronauts preferred holding themselves in place with their shoes fastened to the floor.

The mobility aids and restraints aboard Skylab were very helpful. As the astronauts grew more familiar with their home in space, however, they became adept at restraining themselves by hooking their feet around any convenient protrusion, or wedging themselves between two pieces of equipment until they completed their tasks.

But sleeping crewmen did require restraints.



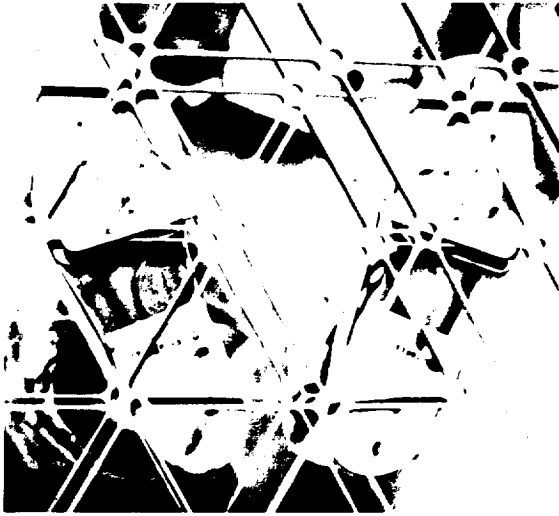
Unsecured objects floated about the workshop and collected on the screens such as this one being vacuumed by Jack Lousma. Crewmen began their search for missing items there.

The bedroom was a small compartment divided into three separate modules, each about the size of a small walk-in closet. Each module was equipped with a bed, a locker, and a doorlike privacy curtain, and each had an adjustable vent through which air circulated.

The bed was a multilayered sleeping bag hung on a frame against the compartment wall. Ready for sleep, the astronaut zipped open his bed, selected the number of blankets he needed for warmth, eased himself between them, and then attached a body strap and closed the zipper. This enclosed him in the pillowed sleeping bag and kept him from floating around as he slept.

Despite sleeping in what would appear to be an upright position against the wall, and despite the absence of gravity, crewmen slept well. Some of the crewmen added their own variation to the sleeping position. Some slept with their heads nearer the floor, while others stretched their beds out like a hammock.

Skylab's interior lighting consisted of a combination of incandescent and fluorescent lights.



Skylab's floors were made up of triangular grids. Triangular shoe cleats fitted into the grid cavities. With a twist of his foot, a crewman could position himself wherever he chose. A number of other types of restraints were also provided.

Seventy-eight fixed lights and five portable lights could be used in any combination to produce the lighting level required to support the astronaut activities. Portable high-intensity lights were used for filming experiments.

The size of the workshop and the necessity for crewmen to work in a number of different locations, as well as to perform extravehicular activity, demanded a reliable system of communications. Also, since the low pressure inside the workshop would not adequately support normal conversation beyond a few feet, audio aids were needed for crew communications.

The workshop intercommunication system was similar to a typical home intercommunication system which permits conversation between people in different rooms of the house. Conversation with the Mission Control Center was a typical two-way radio link.

Intercommunication stations were located at 13 positions within the workshop. Each station provided control for crewman communication as well as communication with the Mission Control Center. The station also included receptacles for a headset and controls which included microphone and transmitter keying, call channel and tape-recorded selection, and volume adjustment, as well

as audible indications from the caution and warning system.

Two types of headsets were provided for the crew. One type included two microphones and two earphones, and could be used in both suited and shirtsleeve operations. The second type contained a single microphone and earpiece and was used in the shirtsleeve mode.

Housekeeping, a Daily Requirement

Housekeeping demanded much of the astronauts' time. Floating around the workshop, tethered to a bracket, holding to a handrail, or with a foot locked around some piece of equipment, the astronaut carefully used a vacuum cleaner to remove such things as hair clippings from the air as well as to clean the workshop surfaces in the conventional manner.

As in most homes, trash disposal became an important housekeeping activity. Nonflammable, biologically inert trash was collected in cylindrical bags made of vented fabric. When filled, these bags were attached to cables inside the area adjacent to the waste tank beneath the crew compartment floor.

Flammable and biologically active trash was

Kerwin prepares to sleep. In the zero-gravity atmosphere, beds were unnecessary. Crewmen zipped themselves into sleeping bags stretched against the wall.





In this photograph, Astronauts Pogue and Carr of Skylab's third crew work together stowing trash bags in the airlock for disposal in the waste tank.

collected in several specially designed types of bags, which were disposed of in the waste tank through the trash airlock.

Skylab's waste tank was part of the liquid oxygen tank located in the aft end of the propulsive stage. A bulkhead separated it from the living area. A network of fine-mesh screens was installed to prevent dumped solids and liquids from migrating into space. It was vented to prevent pressure buildup from the possible growth of bacteria.

The trash airlock extended into the experiment area. It provided a means of passing trash from the pressurized habitable area into the unpressurized waste tank.

Disposing of trash was a carefully executed procedure. The crewman opened a valve which brought the airlock to the same pressure as that within the workshop. He then opened the lid, placed the bagged trash inside, and closed the lid and locked it. By turning the valve handle, he reduced the pressure within the airlock until it reached the vacuum of the waste tank. Another movement of the handle opened the door between the airlock and the waste tank. The crewman then operated an ejector handle, which caused a scissors-type mechanism to push the bagged trash from the airlock into the tank.

Scientific Observations and Experiments

Although the initial crew spent considerable time repairing their damaged space station and in readying the workshop for occupancy, they were also busy conducting scientific observations and experiments.

Early in the mission, Scientist Pilot Joe Kerwin had begun carrying out solar observations using the telescopes housed in the solar observatory.

The experiment canister in the solar observatory had four compartments, each of which housed two of the solar telescopes. Five of these telescopes viewed the Sun in its X-ray and ultraviolet wavelengths, observations that are impossible from Earth. One telescope created artificial eclipses so that the Sun's corona, or outer atmosphere, could be studied. The other two telescopes televised images of the Sun.

The acquisition Sun sensor provided coarse pointing attitude information, describing the space station's orientation relative to the line of sight from Skylab to the Sun.

Pointing large bodies such as Skylab with the extreme accuracies required for solar astronomy was beyond the capability of the control moment gyroscope system. In addition, astronaut activity within the space station caused disturbances in attitude that precluded meeting the required pointing accuracies. This made it necessary for the solar experiment canister to have a separate, highly accurate experiment pointing control system.

This experiment pointing control system consisted of four rate-gyroscope processors (two each

about the pitch-and-yaw axes of Skylab), redundant precise Sun sensors, a manual pointing controller, a roll positioning mechanism, pitch-and-yaw flex-pivot actuators, launch and orbital caging devices, and an analog computer for processing the rate and position sensor information and issuing commands to the actuators. The experiment canister was dynamically isolated from the solar observatory rack through the use of flex-pivot torque actuators in the pitch-and-yaw axes and ring gear in the roll axis. The actuators provided ± 2 degrees of movement in pitch and yaw and ± 120 degrees rotation in roll. The solar north pole was used as the canister roll position zero reference. The center of the solar disk was used for a pitch-and-yaw zero reference.

The mechanism which rotated the canister about the roll axis was controlled by the crew, using the manual pointing controller rate switches on the control and display console. During extravehicular activities, canister roll was controlled by the crew using the EVA rotation control panel, located at a work station on the solar observatory.

Four rate-gyroscope processors, identical to those used in the control-moment gyroscope system, were used for coarse mode canister rate sensing in the experiment pointing control system.

The precise Sun sensor provided the highly accurate information required for the "UP/DOWN" and "LEFT/RIGHT" axes of the experiment pointing control system. Direction control for offset pointing was provided through either the manual pointing controller or the onboard digital computer.

The experiment pointing control system was used to point the experiment canister at selected targets on the solar disk with errors less than 2.5 arc-seconds. Using the manual pointing controller and television display on the control and display panel, astronauts were able to "home in" on selected targets on the solar disk with pointing errors of less than 1 arc-second. Stability of the experiment pointing control system was such that the canister deviation or drift from selected targets was no more than 1 arc-second in 15 minutes.

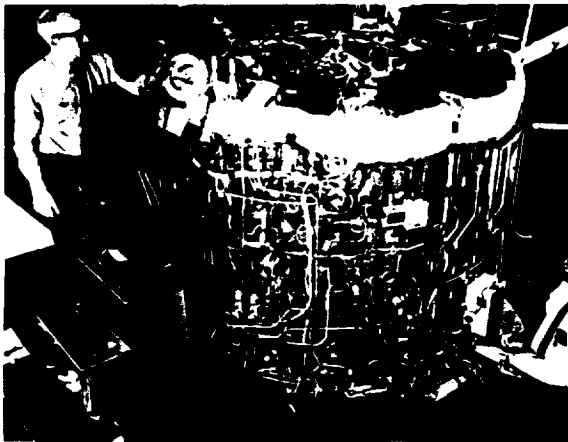
The control and display panel, located in the docking adapter, was the control center for carrying out solar experiments. It also contained the necessary lights, meters, and switches to operate and monitor certain systems throughout Skylab. From this central location, the astronauts sent



One of the crewmen uses a medical light and reflector for better visibility as he works in the experiment area.



Skylab's solar observatory was the largest and most complete such scientific platform ever launched. This photograph provides a view of the octagonal structure with its surrounding truss.



The complexity of the solar observatory canister is clearly evident in this photograph.

commands to experiments and systems with toggle and rotary switches, the manual pointing controller, and the digital address system. The manual pointing controller permitted the crew to point the solar experiment canister and position the star tracker. The two television monitors displayed the five solar experiment video pictures for the astronauts.

Solar observatory canister

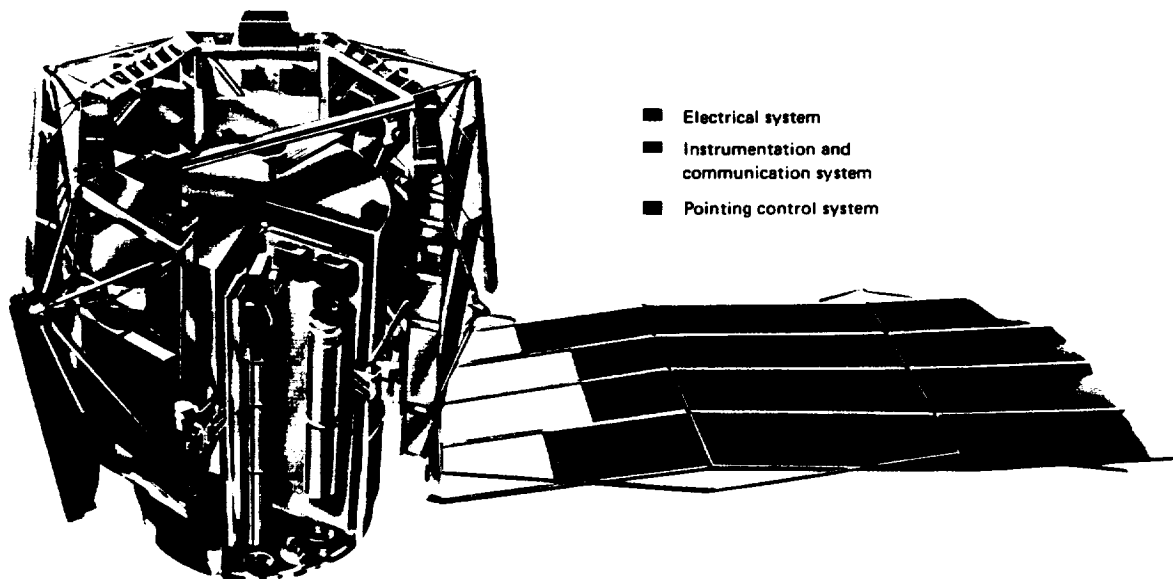
Earth Observations Begun

Observations of the Earth also received considerable attention from the first crew. Most Earth resources data are collected by ships and buoys, sounding rockets, balloons, aircraft, and satellites. Remote sensing of the Earth from orbital attitudes, together with photography in the visible and near-infrared spectral regions, provided valuable additional data. Observations from space offered the advantages of a broad field of view afforded by the increased altitude, periodic coverage of the same area, and coverage of areas otherwise inaccessible. Cameras, radar, and other precision instruments on board Skylab studied the surface of the Earth, surveyed crops, made precise terrain measurements, and detected the formation of storms.

Adjustments to the Space Environment

By mid-June, Conrad, Kerwin, and Weitz held a new space record. They had surpassed the 18-day duration of Soyuz 9. Their bodies had adjusted to weightlessness. Without the influence of gravity, their spines had stretched and they had grown about an inch taller. Their faces had become fatter, as body fluids migrated upward. Nevertheless, their physical condition remained excellent.

Their ability to diagnose problems and their skill





Astronaut Weitz on solar flare watch. All of the solar experiments could be controlled or monitored from this center.



Skylab provided valuable Earth observation studies

in solving them underlined the importance of man in space. Some problems which arose could not have been solved without the crewmen performing some vital activity. An example was the failure of one of the solar observatory power conditioners, which controls energy received from the solar array. The power conditioner consisted of a battery charger, a battery, and a load regulator. Neither the regulator nor the charger would draw power. Ground analysis of the problem indicated that the solar-power contactor had failed in the open position.

Ground engineers who had worked on the system recalled that they had experienced similar problems during laboratory tests. They had observed that a mechanical shock of the contactor would sometimes correct the problem. They recommended that the power conditioner be rapped with a hammer in an attempt to close the contactor. Since the power conditioner was located on the solar observatory mounting structure,

repairs would have to be made during a walk in space.

Working on the ground, engineers simulated the stuck contactor in the power conditioner and determined just where the power conditioner would have to be struck.

"Start at the upper right hand corner," they instructed Conrad, "come down three screws . . . turn to your left, and you go one screw. That's the one you pound on."

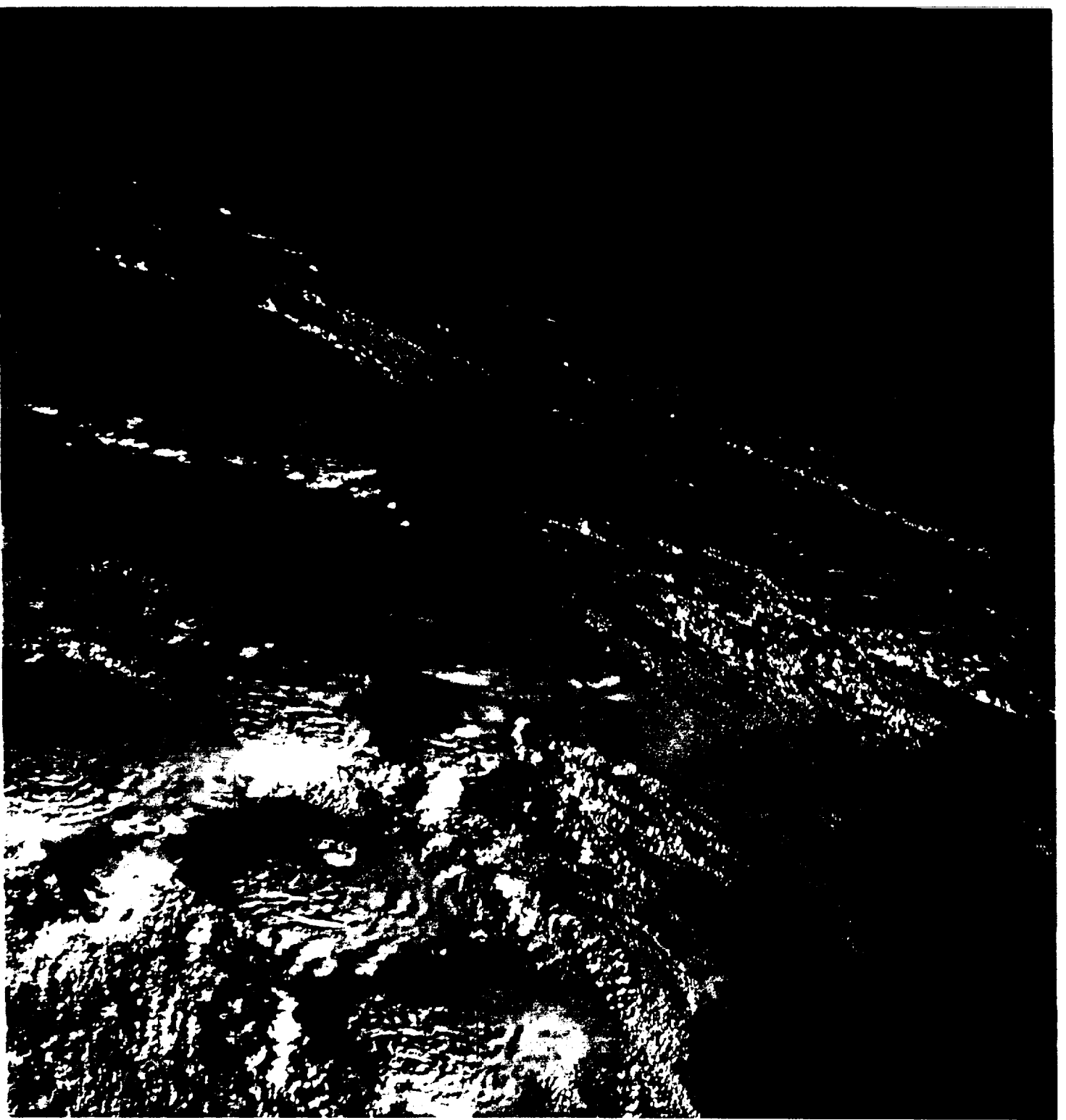
Weitz, outside the workshop with Conrad, reported Conrad's actions to Kerwin, manning the console inside the workshop.

"There it goes. Boy, is he hitting it."

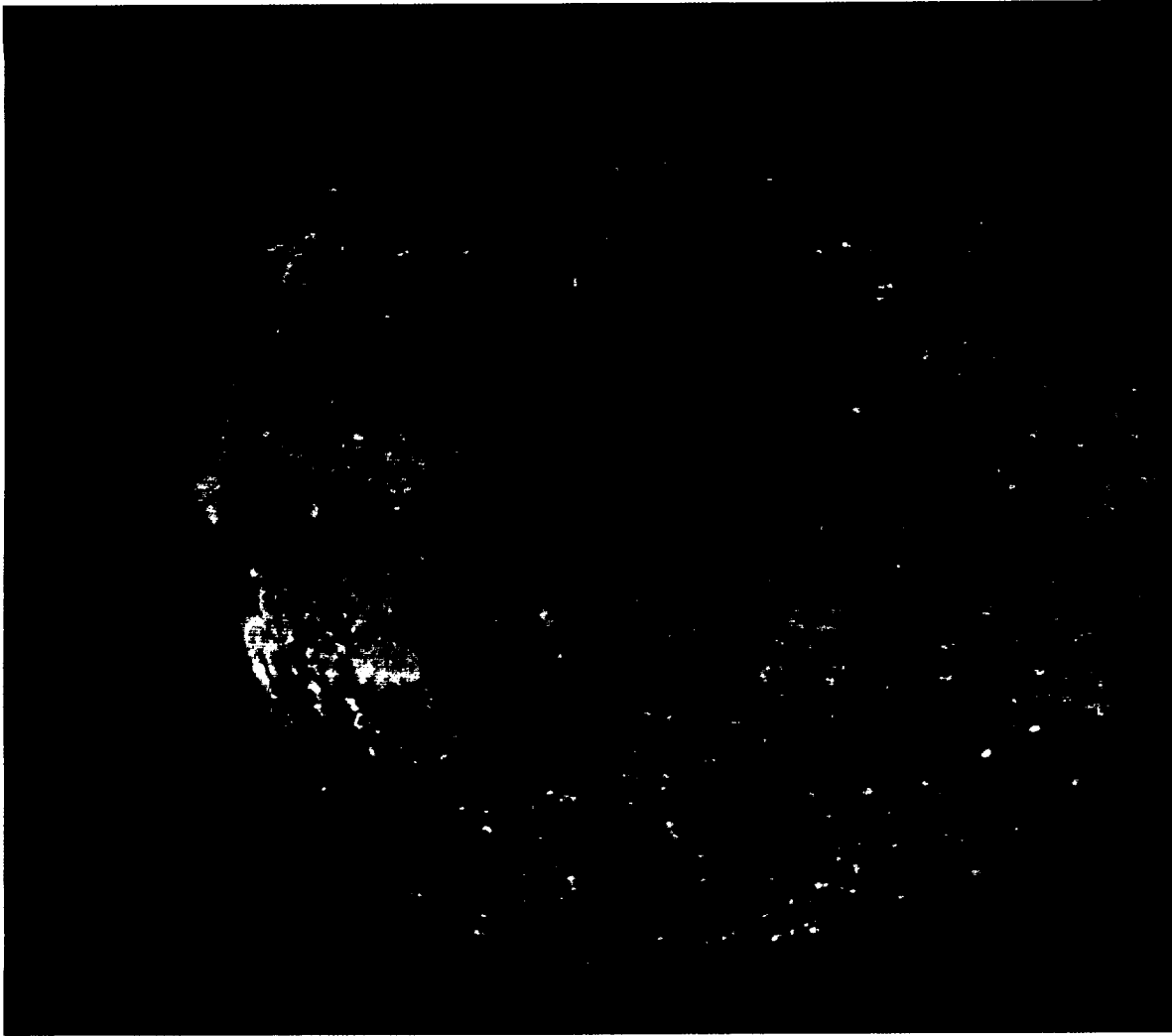
Kerwin then relayed information to the ground controllers.

"He hit it with the hammer. I turned the charger on and I'm getting a lot of amps plus on the battery."

While the solution to the problem was far from scientific, it worked.



From its 270-mile-high vantage point, Skylab photographed features on Earth, such as these large cloud buildups east of the Carolinas, providing a mass of valuable scientific data.



Skylab's cameras recorded thousands of observations of the Sun. Such detailed observations cannot be made from Earth because of atmospheric interference. (NAVAL RESEARCH LABORATORY)

Once again, experience and ground simulation, plus the presence of man, had solved a potentially difficult problem.

As the first manned period was nearing an end, Conrad and Weitz began retrieving the exposed film which had recorded the results of Skylab's experiments.

Film retrieval required that the suited astronauts

work outside the space station for an extended period of time, one remaining just outside the airlock hatch at the airlock shroud work station with the other moving between the center, transfer, and Sun-end work stations to perform film replacement. Two film transfer booms were provided to transport the film magazines to and from the airlock shroud work station and the immediate

work area. Film was held to the booms by a special clamp.

Difficulties With Refrigeration

The refrigeration loop contained a valve which allowed the flow to pass through an external radiator when required by thermal conditions within the loop. The valve was automatically controlled and normally switched to the radiator flow mode for a portion of each orbit. During the deactivation period, the valve failed to operate properly when it was required to switch to the radiator flow mode. Signals received in Mission Control showed a sharp decrease in pressure across the pump and a reduction in temperature of the radiator surface during succeeding orbits. Temperatures in the frozen food compartments began to rise. The secondary loop was switched on automatically after temperatures increased within the loop, but it showed the same problems.

Engineers and technicians at the NASA centers and contractors' plants immediately began extensive ground testing to analyze the problem and to determine its effect on the mission. Tests showed up the most probable cause to be failure of the valve to close its bypass port completely.

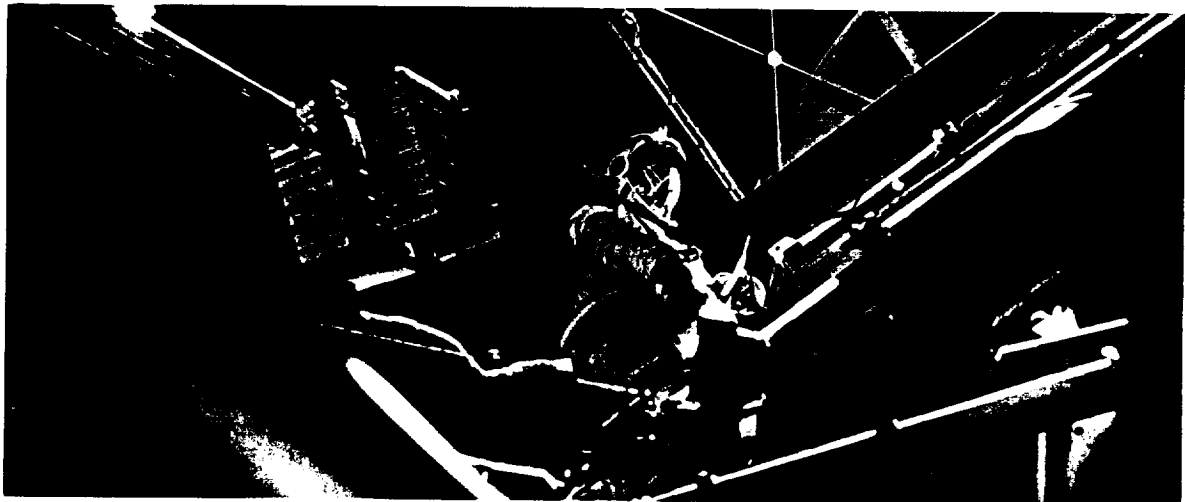
The most logical cause, they determined, was

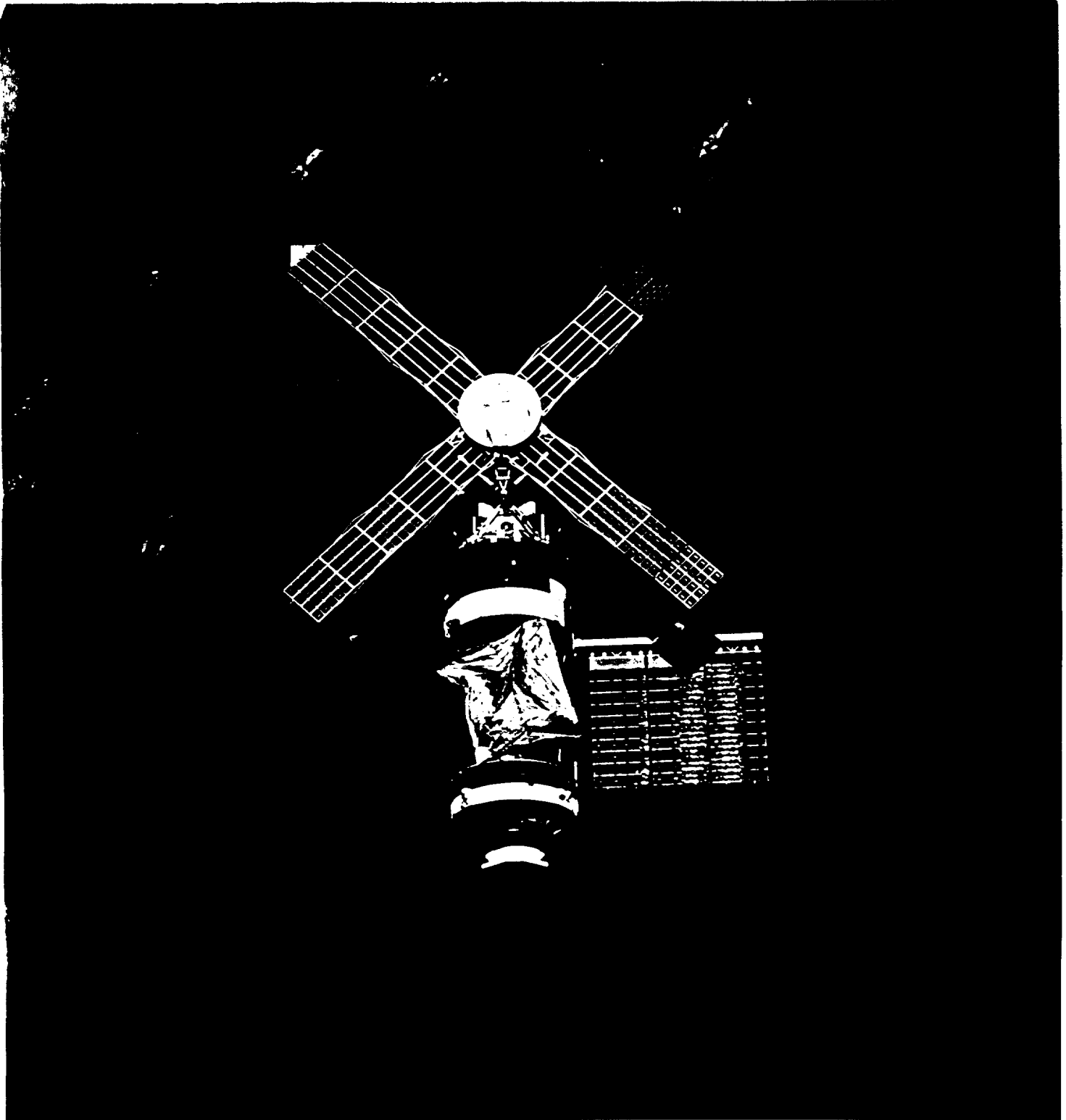
particulate contamination of the valve seat. Moving the valve from one position to the other could possibly clear it. By ground command, both loops were cycled on and off. Cycling the secondary loop valve did not improve its performance. However, the primary loop valve opened enough to allow sufficient flow through the radiator to reduce the loop temperatures to the required values. Temperatures within the loop then remained within the specification limits during the remainder of the Skylab mission.

On June 22, with the command and service module checked out and working properly, and with all necessary equipment stowed for return, the crew undocked and carefully maneuvered their spacecraft about the Skylab, making final observations of its condition and photographing it from every angle. Then, they began their descent into the Earth's atmosphere and splashed down in the Pacific just 800 miles west of San Diego.

They had spent 28 days and 50 minutes orbiting the Earth, far longer than any men before them. During their 404 orbits, they had taken more than 25 000 photographs of the Sun and nearly 7500 photographs of Earth, a wealth of scientific data that would yield valuable information. Moreover, they had proved conclusively that man could live and work effectively in the space environment.

Film retrieval was the final act before departure. Here, film is removed from the solar observatory cameras. Handling in space was made easy by use of a retractable boom.





Before departing for Earth, Skylab's crew made a careful visual and photographic inspection of the space station.



Now unoccupied, the space station circled the Earth at its orbital altitude. While unmanned, it operated at reduced power and with many of its systems either inoperative or operating at reduced capacity. But Skylab was now a fully operational space station, its scientific value well established.

6

The Space Station Unmanned

Skylab continued orbiting the Earth once each 93 minutes.

Without a crew aboard, its requirements for system operation were reduced. But it still needed electrical power for the transmission of technical data to ground controllers, and for retaining a spacecraft attitude and environment suitable for systems operations.

After the first crew departed from the space station, ground controllers lowered workshop internal pressures from 5 to 2 pounds per square inch. This reduced the dewpoint to about 35°F and prevented condensation in the workshop, as temperatures in the unoccupied workshop decreased.

Communicating With Skylab

The ability of ground crews to determine the exact condition of components of operating systems aboard Skylab was vital to mission success. Even with highly skilled crews aboard, it would have been impossible for crewmen to record the vast amount of data, to analyze it, and to take corrective action in the limited time available. With this burden, they would not have had time to carry out their assigned activities.

A dependable system for acquiring and communicating information and for providing radio contact for the control of Skylab was extremely important.

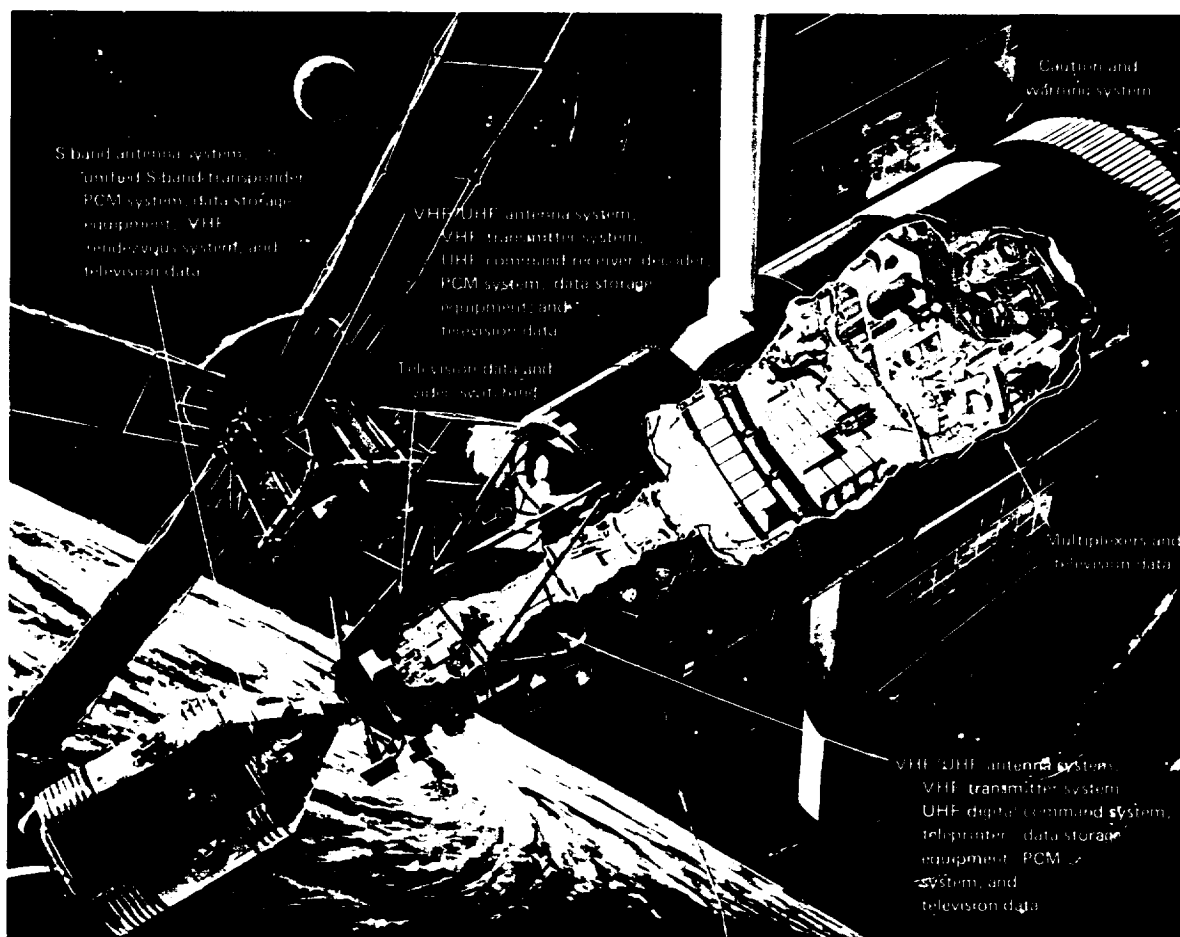
Throughout the Skylab mission, this instrumen-

tation and communication system provided a continuous monitoring of the space station during both manned and unmanned portions of the mission. It provided two-way voice communication between flight crews and ground personnel, and it included a means for transmitting printed instructions to the crew each day. Data obtained during experiments and science demonstrations were transmitted over this system. And crew activities and some scientific observations were transmitted to ground observers by means of television.

More than 2000 separate measurements were made of temperatures, pressure, displacement, flow, voltage, current, vibration, the position of mechanical devices, and other necessary information. Such measurements, made by carefully placed sensors, were converted into electrical signals, which were then transmitted to ground receiving stations.

Thirteen ground stations, located throughout the world, made up the Skylab tracking and data network. They received data directly from Skylab about 32 percent of the time; the remainder of the time, data were recorded on tape and subsequently transmitted to a ground station when Skylab passed over it.

The frequency of measurements varied widely. Since most temperature changes occurred relatively slowly, temperature measurements were made at a rate of from 0.42 to 1.25 samples each second. Some of the solar observatory computer output measurements were made at a rate of 120 samples



Data and communications system

per second, and many of the biomedical measurements were made at the maximum rate possible.

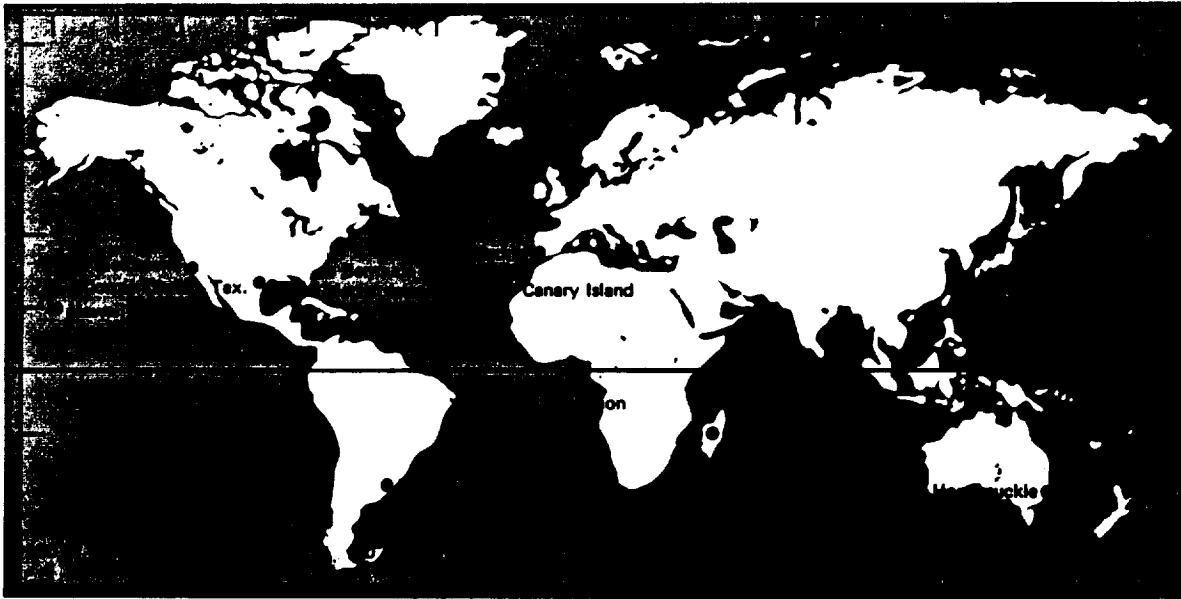
Two separate command systems made it possible to control Skylab from the laboratory or from the ground. The solar observatory system allowed the crew full control while the laboratory was manned and allowed limited control of the solar observatory from the ground. The second system provided both crewmen and ground controllers a means of controlling systems operation in the airlock, the docking adapter, and the workshop.

Command signals to the solar observatory, transmitted from ground stations, were coded so that specific functions would be performed.

A digital command subsystem made possible

some 540 distinct commands, which permitted positive control over the space station at all times. Such commands were received, transmitted through command receivers and decoders, then translated into commands.

The workshop decoder also provided a digital output to the teleprinter, the first such device ever used in a spacecraft. The teleprinter received coded data, converted the data into dots on a matrix, and printed patterns of dots to form messages on thermally sensitive paper. This teleprinter played an important role in the daily lives of the crews, as almost all instructions to them were relayed by this means while they slept. Without it, much more extensive and time-consuming voice communica-



The 13 Earth-based stations making up the system that was able to communicate directly with Skylab throughout the mission.

tion would have been required, with considerably greater possibilities for error.

The capability to observe operation of the space station systems and to control them through selected commands made it possible to continue a program of scientific observation even with the space station unmanned.

Solar Observations Continued

Solar observations were continued in an effort to learn more about the star whose existence makes possible life on Earth. The solar observatory's telescopes had given scientists an intimate look at a Sun radically different from that which they had known before. Unhindered by Earth's atmosphere, its eight telescopes had observed a surprisingly violent surface with mysterious bright points enveloped in a vast and turbulent corona. Ground controllers operated the fine pointing control system to observe selected targets on the Sun.

Use of this control system was limited to the daylight portions of each orbit. At true sunrise, the computer opened the door protecting the precise Sun sensor. At effective sunrise (when the Sun was

above Earth's atmosphere) the computer released the Sun sensor and commanded the controller. The controller then uncaged the canister housing the telescopes by disengaging the orbital locks and began commanding the up-down and left-right actuators which accomplish precise pointing.

On the 64th day of the mission, while Skylab was still unmanned, the primary up-down rate gyroscope processor became very noisy and eventually failed. Since Skylab was out of contact with the ground tracking network when the failure occurred, an entire orbital day phase passed before the problem became evident. The canister began to oscillate about the up-down axis until the actuators overheated and seized, and the system was turned off. Three days later, after extensive analysis by ground crews, the secondary up-down rate gyroscope was selected, and the system was turned on again. No further problems were encountered with the actuator.

Electrical Energy Vital to Station Operations

Skylab was exposed to sunlight for varying periods of time, because of the orbital inclination of the Skylab mission. The maximum period of



Commander Carr reading a teleprinter message. Instructions to flight crews were often transmitted by teleprinter. Skylab was the first such craft to be equipped with the capability to receive messages by this means. While the crew slept, flight plan changes, procedures, and instructions were transmitted and recorded on board.

darkness was 26 minutes. There were orbits in which Skylab was in continuous sunlight, during which orbital night did not occur. The continuous sunlight periods occurred only three times during the 273-day mission, for a total duration of 10 days. While Skylab was in orbital daylight, its solar cells drew energy from the Sun for conversion into electrical power. But when it passed through periods of orbital night, power had to come from the batteries. This required that sufficient power be generated during orbital daylight to operate the

Skylab systems and also to charge the batteries. Calculations resulted in the decision that the solar cell array be sized electrically to be $2\frac{1}{2}$ times the space station load.

Power sharing between the solar observatory and the workshop electrical power systems was controlled by adjusting the voltage of the laboratory power system. By increasing the workshop output voltage, its system supplied a larger percentage of the load. Conversely, by decreasing the workshop output voltage, the solar observatory supplied an

increasing percentage of the load. If equal load sharing was desirable, the workshop voltage could be adjusted so that both systems supplied one-half of the total load.

To transfer power from Skylab to the command and service module, the astronauts connected an umbilical cable in the workshop to the spacecraft, and circuit breakers and switches were operated for power transfer. The cable was installed at the beginning of each manned mission.

The flexibility of this system was demonstrated vividly during the early days of the Skylab mission.

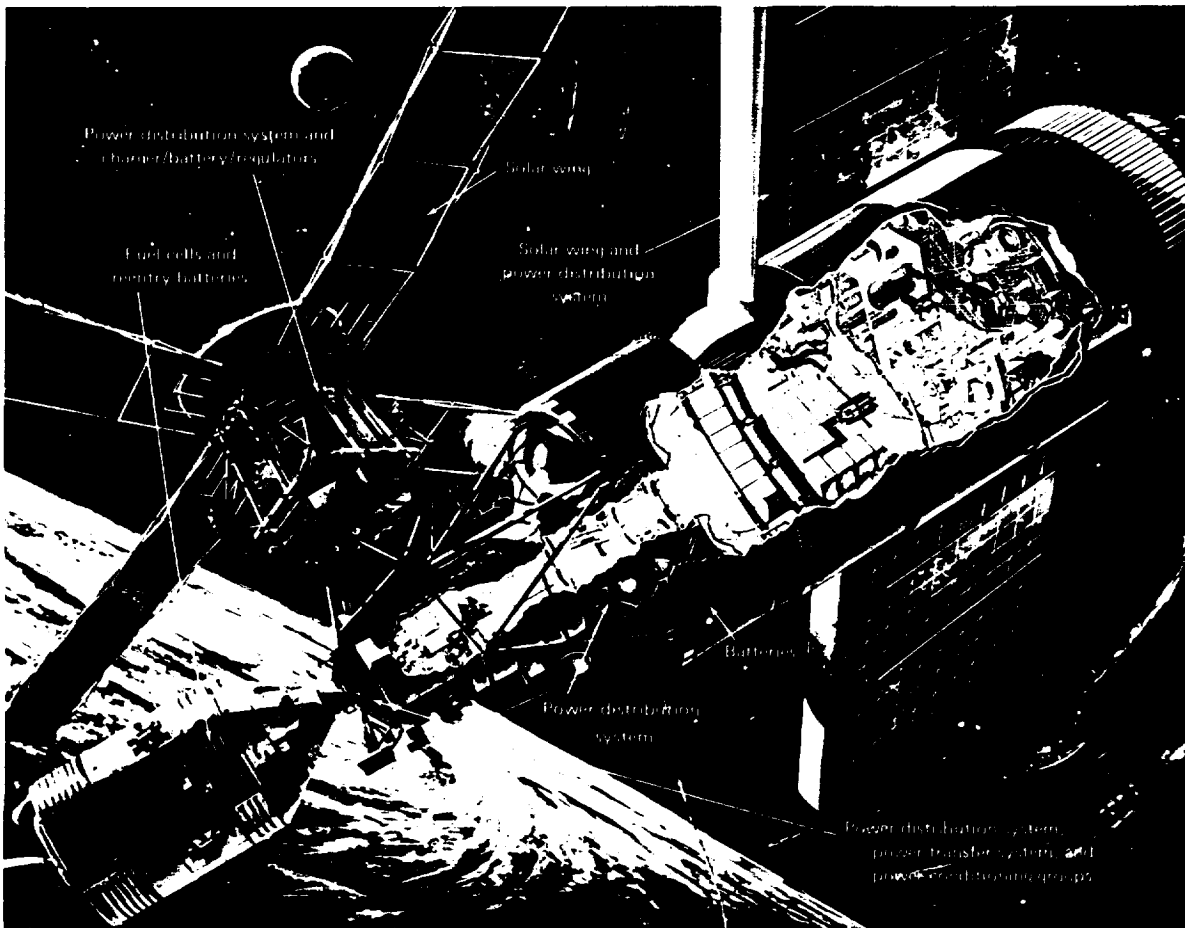
For the first 11 days, the solar observatory electrical power system was the only source of power. On the 12th day, the Apollo command and

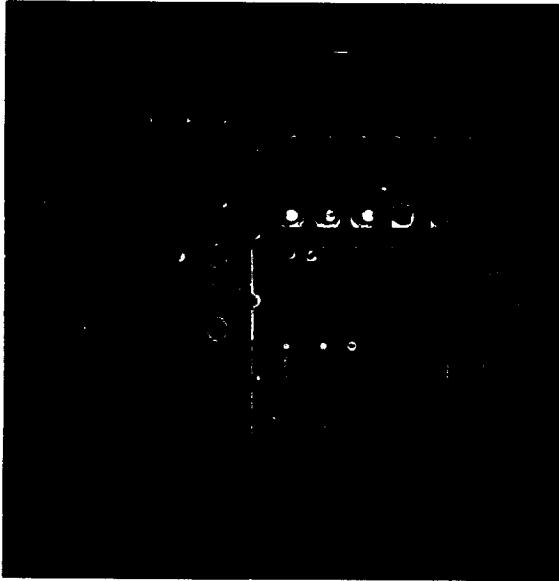
service module docked with Skylab. Its fuel cells continued to supply the command and service module load, while the solar observatory system provided all the power for Skylab activities until the workshop solar wing was deployed on the 14th day of the first manned period.

Power Management Needed for Mission Success

Skylab designers had foreseen the possibility of problems arising and had made plans for management of electrical power under a wide range of conditions. During the initial period of dependence upon the solar observatory power generation system, prior to freeing and deployment of the

Electrical power system





Electrical panels contained instruments showing the condition of electrical equipment, and switches and controls for their operation.

workshop solar wing, it became necessary to implement effective management of the available power. This required constant monitoring of all electrical power system parameters, knowledge of the exact vehicle electrical load at all times, and precise knowledge of the requirements of each subsystem for all mission phases. With this information, engineers reviewed all planned Skylab activities and evaluated the capability of the electrical power system to support them. Next, they predicted total electrical load requirements and system performance. And finally, power management techniques were developed to satisfy the requirements.

For the first 11 days of the mission, the principal technique was simply to eliminate or reduce power requirements as much as possible. Power to nonessential, manageable loads, such as internal heaters, coolant pumps, telemetry transmitters, and redundant gyroscopes, was either turned off or reduced.

A second means of power management was reduction of the time Skylab was not pointing its arrays at the Sun. But this could be done only at the expense of other vital considerations, such as

holding temperatures to a tolerable level within the workshop.

The first crew was very conscious of the need for careful power management. They were careful to turn off lights, fans, food trays, cameras, experiments, and other power-consuming pieces of equipment when they were not needed.

Preparation for the Second Manned Period

While Skylab, unmanned, continued its orbit, ground crews were busily preparing for the second manned period.

Alan Bean, the commander of the second crew, had explored the Moon. Owen Garriott, the scientist pilot, had taught electrical engineering at Stanford University. Jack Lousma, the pilot, had served as the communicator in Mission Control during the Apollo 13 flight. All had gone through extensive training in preparation for the Skylab mission.

The crew had spent many hours training in the deployment of a second parasol, which had been developed and fabricated between the first and second manned periods and in the deployment of the twin-pole shield stowed in the workshop by the first crew.

As they roared into space just after 7 o'clock on the morning of July 28, 1973, they carried with them a "six-pack" of rate gyroscopes, cables, the improved parasol, experiment film, food for a 3-day mission extension, various assemblies needed to replace failed experiment components, and two laboratory data tape recorders. Also on board were 2 Mummichog minnows and 50 minnow eggs, 6 pocket mice, 720 fruitfly pupae, and 2 common Cross spiders named Arabella and Anita.

The launch had originally been scheduled for 3 weeks later, but the rate gyroscopes aboard Skylab were degrading rapidly, and it was possible that the thermal shield was deteriorating. This made it desirable to have repairs made as soon as possible. Also, the second manned period was extended 3 days beyond the planned 56 days to allow more worktime and to permit a more favorable splash-down area.

Eight hours after launch, Lousma called out, "Here's our home in the sky." Skylab had been sighted.

Two methods were used for rendezvous and docking of the command module with Skylab.

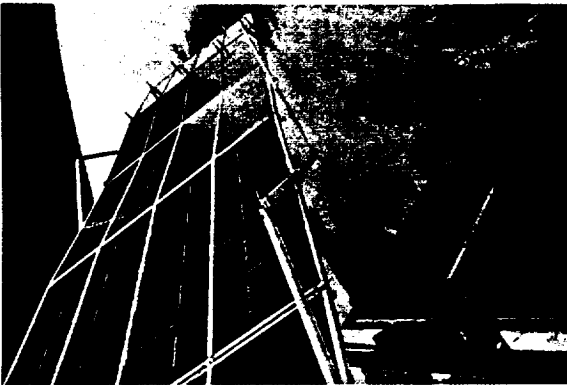
Electronic equipment provided radio contact for ranging information and visual aids were used for the final phase of rendezvous maneuvering and docking.

The very-high-frequency rendezvous and ranging equipment determined the closing rate and distance between Apollo and Skylab. During rendezvous the Apollo command and service module transmitted a tone-modulated signal to the space station where a transponder received and retransmitted this signal. Command and service module electronics demodulated the retransmitted signal and measured the phase differences to compute the distance between the two vehicles.

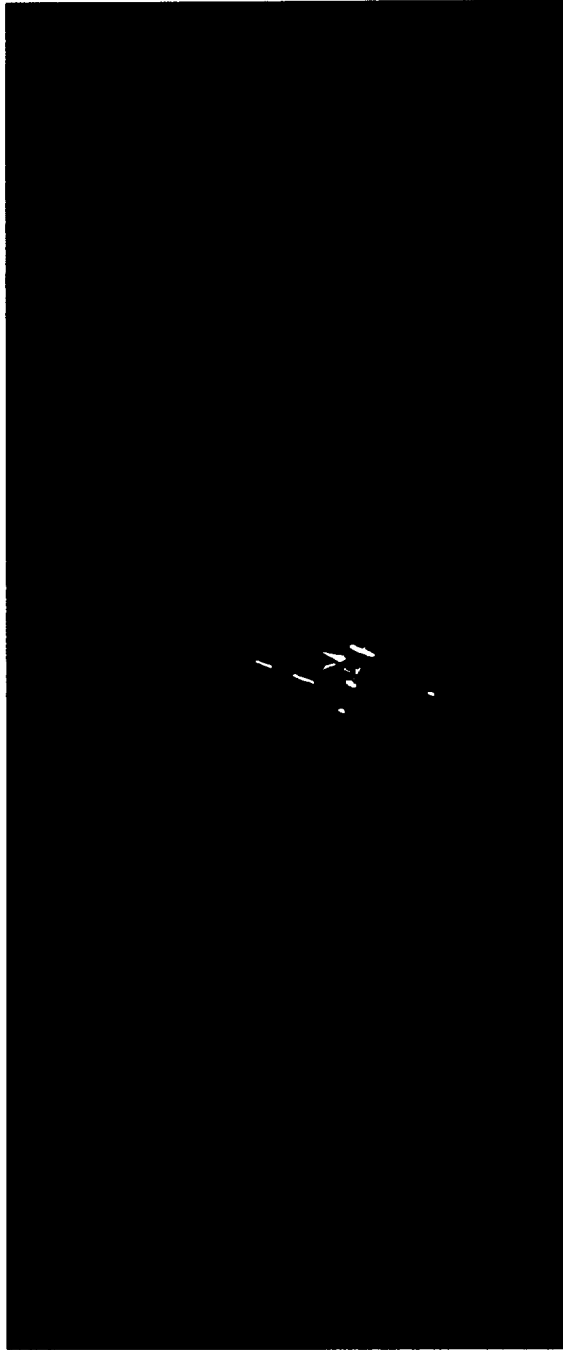
Skylab was visually sighted from as far away as 390 miles by its crew. Four flashing lights, mounted on the solar observatory, made Skylab clearly visible. Eight docking lights were mounted on the workshop structure and color coded to indicate its orientation. Four smaller bulbs illuminated the tips of the discone antennas. The astronauts used these lights to orient the Apollo module for safe docking, after which they turned them off until their departure at the end of their mission.

Exterior lights illuminated the workshop, airlock, and the solar observatory work station during extravehicular activities.

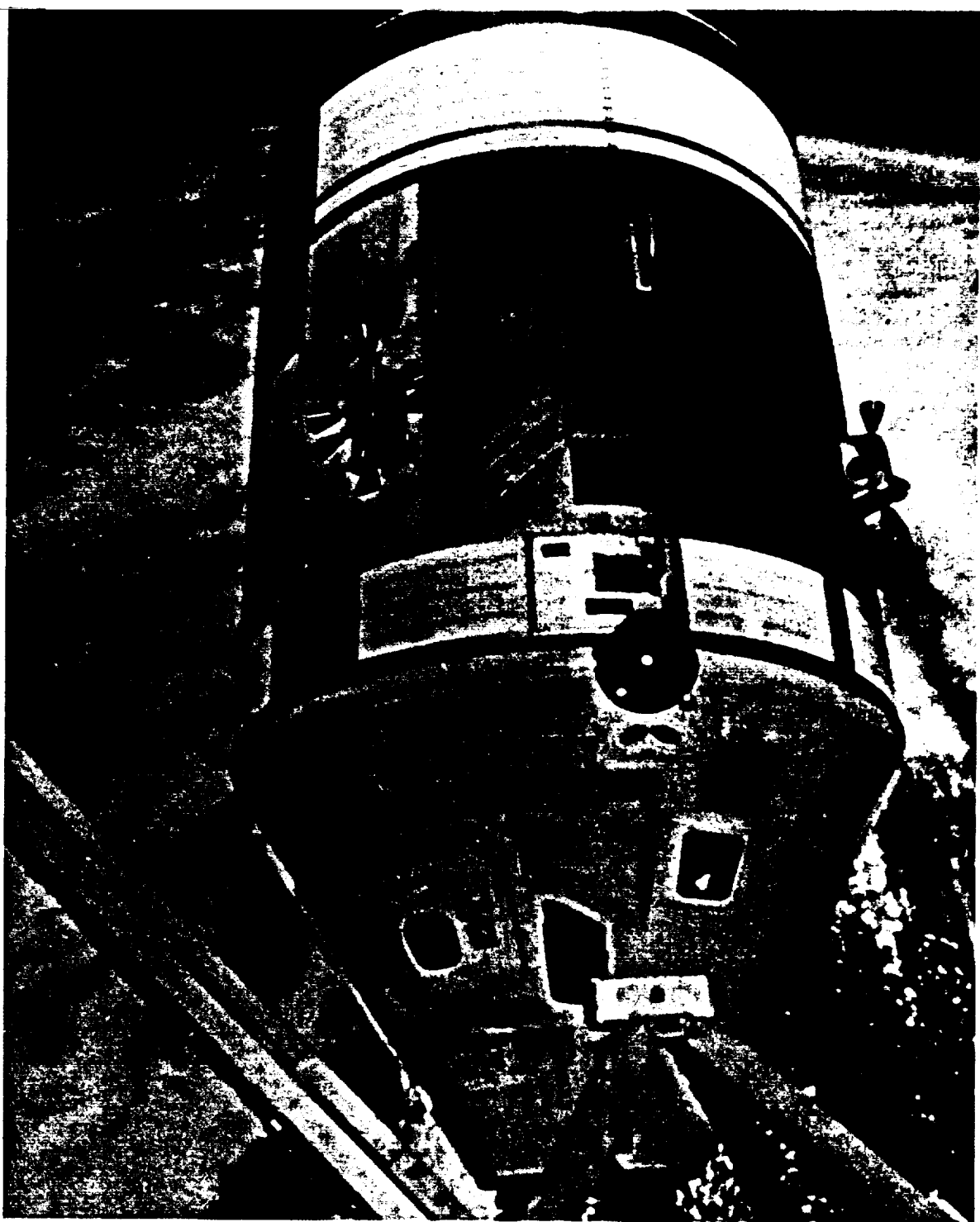
Once docked, the crew opened the hatch leading to Skylab and began the job of transferring supplies and preparing Skylab for the second manned period.



The solar observatory and workshop solar arrays drew their energy through panels containing thousands of small solar cells.



The unmanned Skylab could be sighted from great distances by its flashing lights.



Four sets of thrusters (two of which are shown here), each consisting of four engines, controlled the attitude of the command and service module. Apparent difficulties with these engines early in the second manned period caused concern, since the thrusters were vital to the mission.

7

The Second Manned Period

Skylab's second crew discovered quickly that space missions are never routine.

Ground controllers had prepared Skylab for their visit by increasing the temperature and raising the pressure inside the workshop to 5 pounds per square inch once more. As the command and service module approached Skylab, the docking lights, transponder, and tracking lights were sequenced to assist in the rendezvous and docking maneuver.

During these rendezvous maneuvers, Commander Bean reported seeing "some kind of sparklers." At the same time, ground controllers noted a pressure drop in one of the four thruster assemblies which steer the command module, and concluded that its propellant was leaking. The thruster unit was shut down, and the crew docked, using the remaining three thrusters.

Six days later, ground controllers noted a pressure drop in another of the thrusters and shut it down, also. The apparent loss of this second unit began to cause concern.

The command and service module control system consisted of four individual assemblies, each of which had four engines and a separate propellant feed system. The engines were mounted in a housing which also enclosed an oxidizer and a fuel manifold that fed propellants to the thruster solenoid valves. Readings of system pressures and temperatures indicated that oxidizer was leaking inside the engine housing.

These thrusters were vital to operation of the

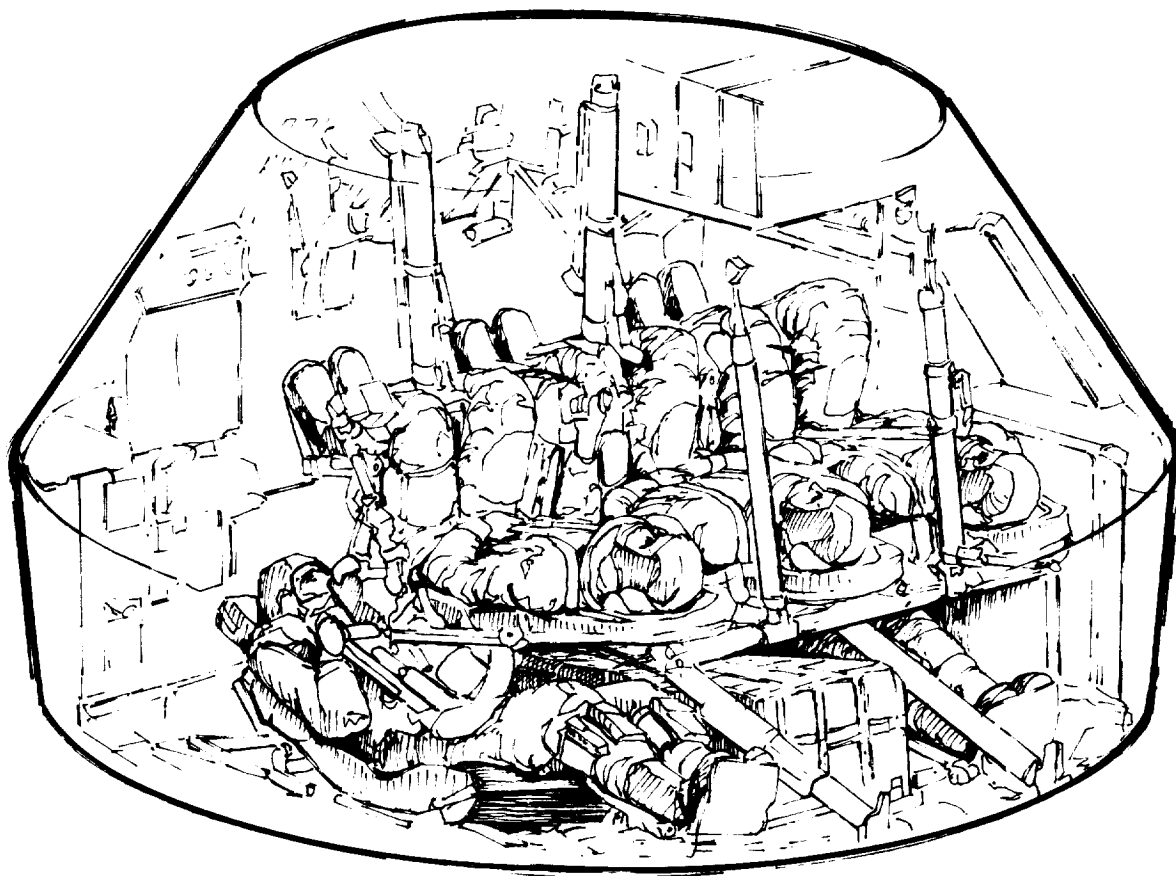
spacecraft, since they oriented it so that its main rocket could fire in the proper direction for safe reentry into the Earth's atmosphere as the crew returned to Earth. With the possible loss of the second thruster assembly, Mission Control personnel began making plans for terminating the mission and for rescuing the crew, if this should become necessary.

Rescue Mission Considered

The Skylab mission had always included provisions for rescue of the crew in the event that the Apollo module lost its capability to return the crew safely to Earth. Loss of two of the four thruster assemblies would jeopardize completion of the mission, so rescue became a strong consideration.

The rescue vehicle was an Apollo command and service module modified by removing the storage lockers on the aft bulkhead and installing two couches in that space, and by providing life support and communications umbilicals to accommodate a total of five crewmen who would return to Earth in it. For a rescue mission, two crewmen would occupy the rescue vehicle as it ascended into orbit. The center couch would be empty. Upon docking with the space station, the two crewmen of the rescue team would enter the space station and return with the three-man Skylab crew. Then they would return to Earth in the rescue vehicle.

Engineers analyzing information relayed to them



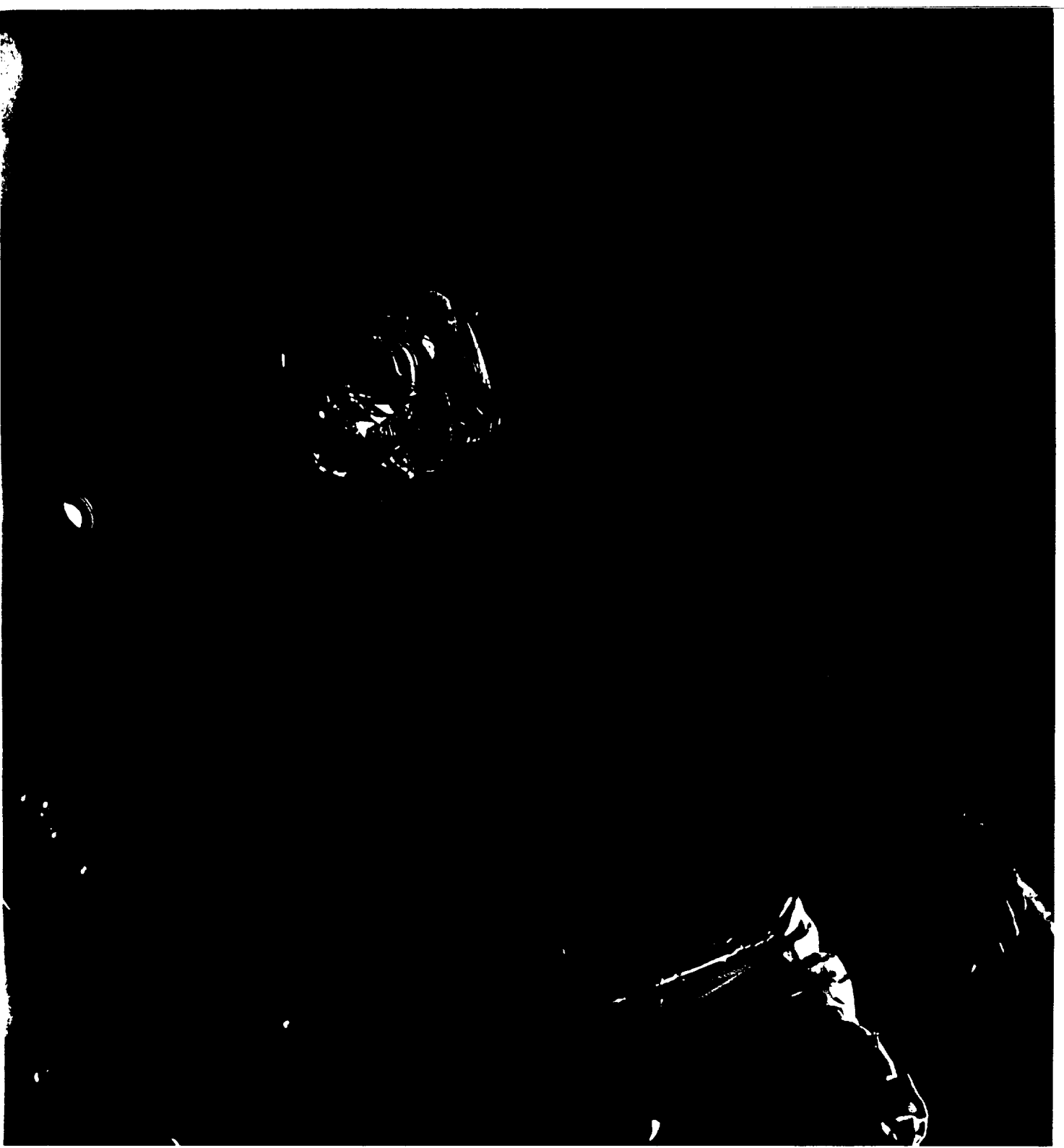
The rescue craft was an Apollo command module, modified to accommodate five persons. This sketch shows the rescuers and the rescued prepared for reentry of the Earth's atmosphere and a water landing.

by instrumentation theorized that the leaks in the two thruster assemblies were unrelated. One appeared to be caused by a leaking valve, the other by loose fittings. The two remaining thruster assemblies checked out perfectly, and the decision was made to continue the mission, as planned. Computer studies and ground simulations showed that the spacecraft could be steered successfully with only two thruster assemblies, if this should become necessary. So, ground controllers advised Bean, Garriott, and Lousma that they would remain aboard Skylab for the full 59 days. Engineers used ground mockups and engineering data to develop procedures for checking out the

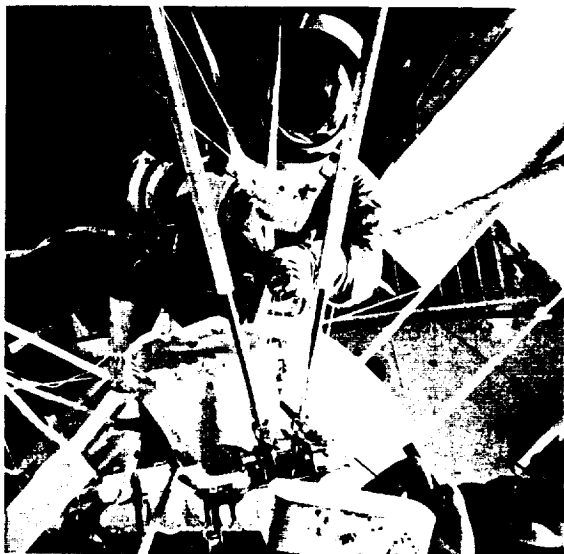
thruster assemblies upon preparation for departure at the conclusion of the manned period.

Meanwhile, another but less serious problem arose. Shortly after reaching orbit, before rendezvous with the Skylab, Pilot Jack Lousma began to experience motion sickness. Each movement of the command and service module further aggravated this condition. An anti-motion-sickness pill relieved the condition so that he could participate in activating the space station upon docking. But the heavy workload further aggravated his condition, and he became nauseated after eating his first meal.

Later in the day, Bean and Garriott also experienced motion sickness. All three crewmen were



Astronaut Jack Lousma begins the extravehicular activity to erect the twin-pole shield to shade the workshop.



This photograph, taken in the neutral buoyancy simulator, shows the base plate which was fabricated to hold the twin poles in place. Also shown is the bag which held the fabric sail and the lines by which it was drawn into place. Deployment procedures were carefully worked out in the simulator.

slowed by this malaise during the first 3 days, after which the symptoms subsided. By the end of the fifth day, all three astronauts had regained their strength, and were working without difficulty.

Nasal congestion, which had been noted during the first manned visit, became very evident in their voice communications between the end of the third day and the early portion of the fourth day. The condition was barely noticeable to the crewmen themselves, and it caused them no discomfort.

While motion sickness slowed crew activities somewhat, it did not prevent their carrying out several highly important maintenance tasks which contributed significantly to Skylab's success.

New Sun Shield Erected

On August 6, 1973, Garriott and Lousma performed an extravehicular activity which lasted 6 hours and 31 minutes, a new world record for spacewalks. During this time, they loaded film canisters in the solar observatory telescopes, installed panels to measure micrometeoroid impacts, and inspected the Apollo command and service module thrusters; they found no evidence of

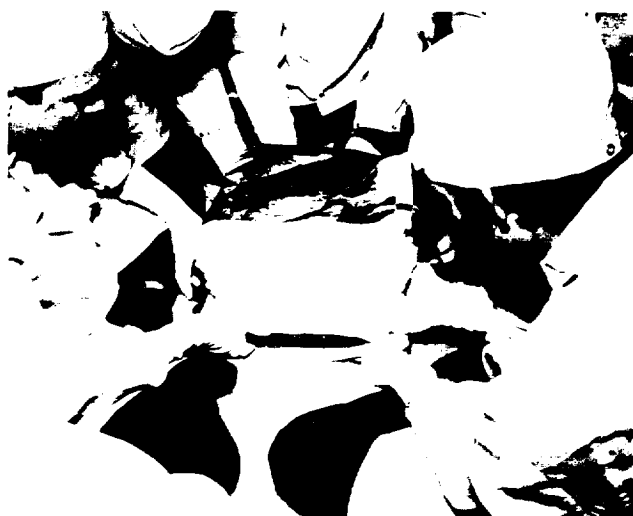
further leakage. They also erected a new solar shield over the parasol, which had protected the workshop since erection by the first crew, 71 days earlier.

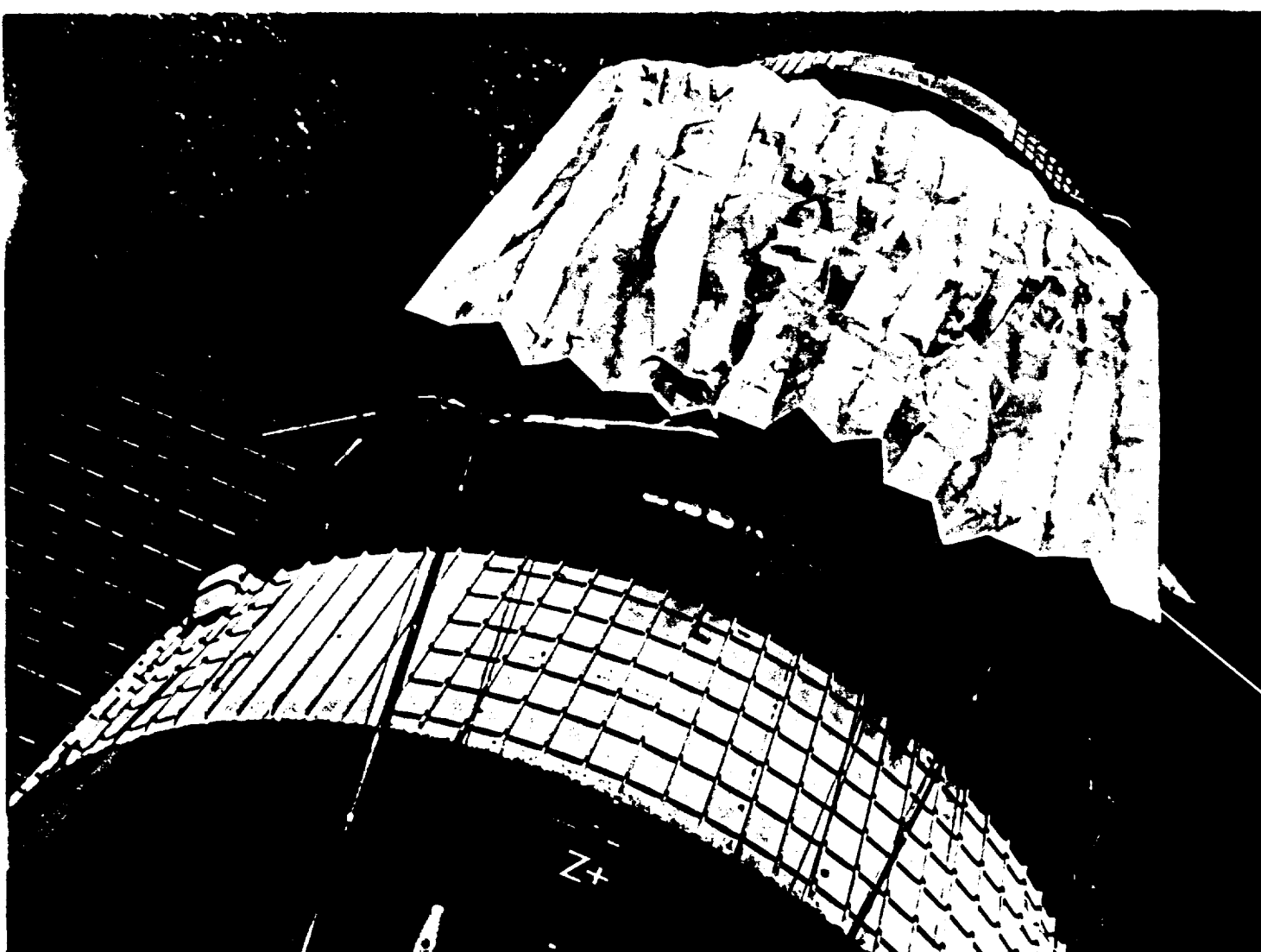
The twin-pole shield, made of fabric treated with a silicone rubber-based paint for thermal control, was designed to be suspended on a twin-pole A-frame made of long aluminum poles, the apex of which was to be attached at the solar observatory work station. This shield and the poles for erecting it had been transported to Skylab by the first crew and stowed for subsequent use.

Before going outside Skylab, the crew lowered the parasol shield to a position as close to the workshop as possible. Next, Lousma crawled through the airlock hatch and worked himself hand over hand along handrails to the base of the solar observatory, where he mounted temporary foot restraints. Garriott used the extendable boom to transfer a base-plate fitting to Lousma. This fitting had been specially fabricated and was designed to hold the two sail poles firmly in position over the workshop.

While Lousma clamped the base plate to a solar observatory outrigger, Garriott stood near the open airlock hatch and assembled the 55-foot pole from eleven 5-foot sections, feeding them to Lousma as

Highly experienced Navy Seal Team members, professional parachute riggers, used a unique accordion fold to pack the twin-pole shield before it was stowed in the command module.





Concern over the possibility that materials used for the parasol would deteriorate with prolonged exposure to the Sun's rays and that more complete shielding was required to better control workshop temperatures prompted the installation of a second Sun shield during the second manned mission. This time the crew exited the space station and installed a twin-pole device to position the shield over the parasol.

he constructed it. As Lousma received the poles, he positioned their base end into the two V-shaped receptacles on the base plate.

The outward section of each pole had an eyelet through which a continuous loop of rope was threaded. Again, using the film transfer boom, Garriott passed the thermal sail package to Lousma, who hooked two corners of the folded sail onto attach rings secured to the ropes. Then he gradually pulled the ropes, sending the sail out

along the poles in a manner similar to raising a flag. When the sail was fully extended along the poles, he tied off the ends of the sail to the solar observatory outrigging.

The Second Crew at Work

Skylab's second crew soon settled down to its new routine. The three astronauts found their home and workshop clean and ready for occupancy, with all systems functioning. Adjusting to



The twin-pole shield was successfully erected over the parasol. A rectangular fabric shield, which was thermally treated, it remained in place for the remainder of the mission.

the zero-gravity environment, they found that they could easily work long hours without fatigue.

With Skylab's systems in operation, the total power load was about 3900 watts, considerably less than the 5500 watts average power capability then available in Skylab. After full operations began, the average load requirement was 4800 watts for the first 20 days of the mission, and 5850 watts thereafter; but the power system's regulated voltage was increased, resulting in a total capability of 7000 watts. Flexibility of the power system made it possible to maintain the necessary power margin for conduct of all phases of the mission. As the mission progressed, the astronauts and ground controllers adjusted the sharing of power between the two systems to be sure that the required power margin was maintained and that batteries were not discharged excessively.

Settled comfortably in their new home, the second crew began carrying out extensive scientific experiments and observations.

Earth Resources Experiment Program

One of their principal activities was execution of the Earth resources experiment program, which

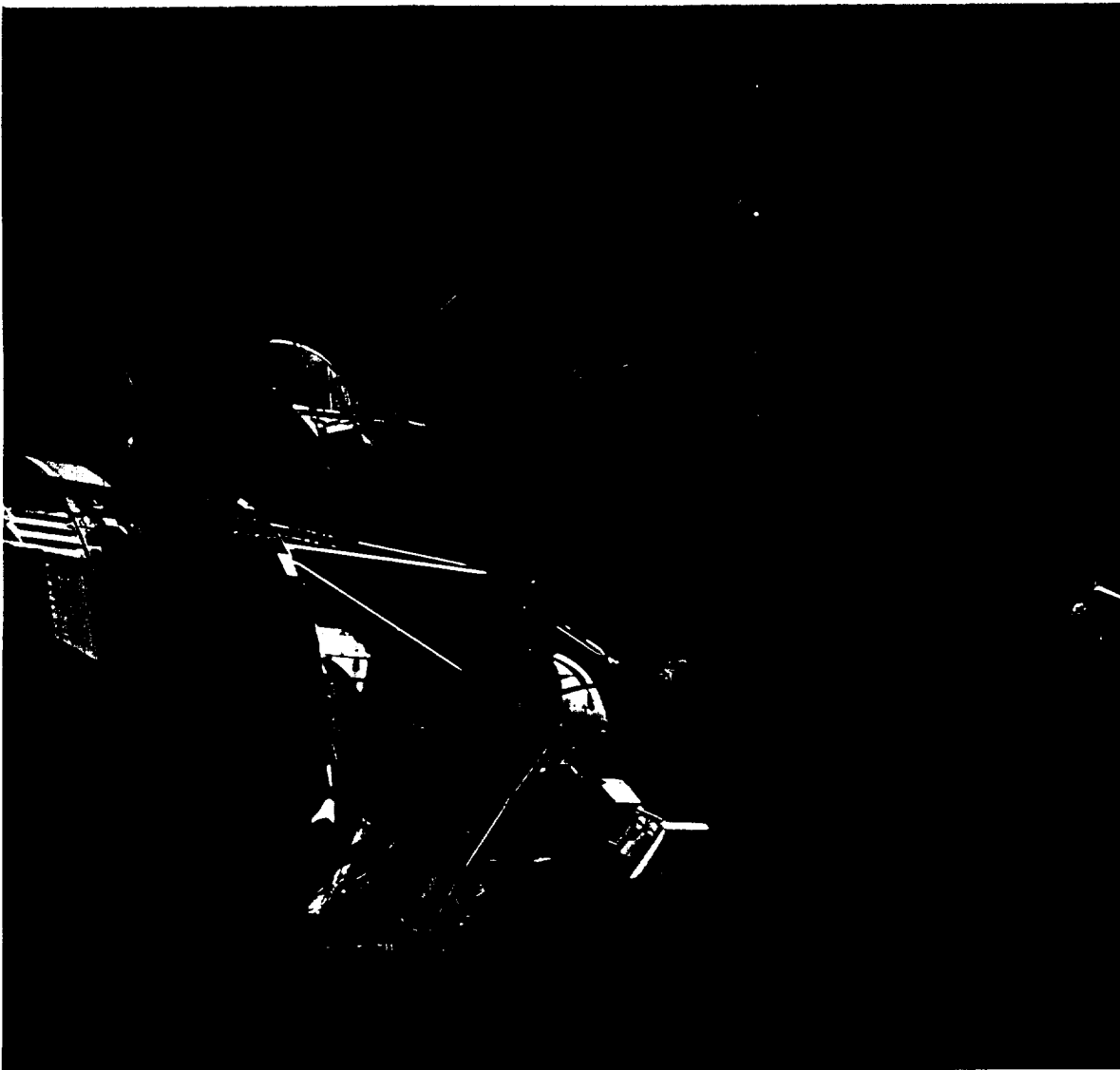
was designed to furnish a variety of observational data about areas at or near the Earth's surface. During the second manned period, Astronauts Bean, Garriott, and Lousma made nearly 16 000 photographs of Earth and recorded scientific data on about 18 miles of magnetic tape.

Earth observations required a reorientation of Skylab from its Sun-observing, or solar inertial, position to one which allowed the Earth resources sensors, mounted in the docking adapter, to point toward the Earth. In this Earth observation attitude, the space station was placed so that the side of the docking adapter opposite the solar observatory always faced the Earth. By contrast, in the solar inertial mode the spacecraft did not rotate as it orbited the Earth, but kept its solar arrays perpendicular to the Sun at all times.

The Earth resources experiment program used a variety of scientific instruments to record data. Six major instruments recorded data in the visible, the infrared, and the microwave regions of the spectrum. These were a multispectral photographic camera, an Earth terrain camera, an infrared spectrometer multispectral scanner, a microwave radiometer/scatterometer and altimeter, and an L-band radiometer. The first four instruments were used to survey crop lands, watersheds, forest areas, geological formations, and cultural features in selected areas. Data from such instruments recorded the type and moisture content of soil, the health of vegetation, insect infestation areas, land use, and population distribution.

The multispectral camera employed high-precision lenses and three different kinds of film to record data concerning the Earth never before obtained in such detail and scope. For example, a survey of the Northern Great Valley of California was made to determine identification accuracy in an area of rice and alfalfa fields, orchards, fallow fields, and dry lands. Color infrared photographs recorded data for agricultural crop surveys. The multispectral scanner measured radiation emitted from ground targets in 13 discrete frequency bands to determine characteristic Earth surface features such as lakes, grass, deciduous forests, and urban developments.

The Earth survey data covered most of the United States and parts of 33 other countries. The photographs and data supported studies in ecology and environmental quality, agriculture, forestry, mapping, geology, water resources, fishing, ocean-



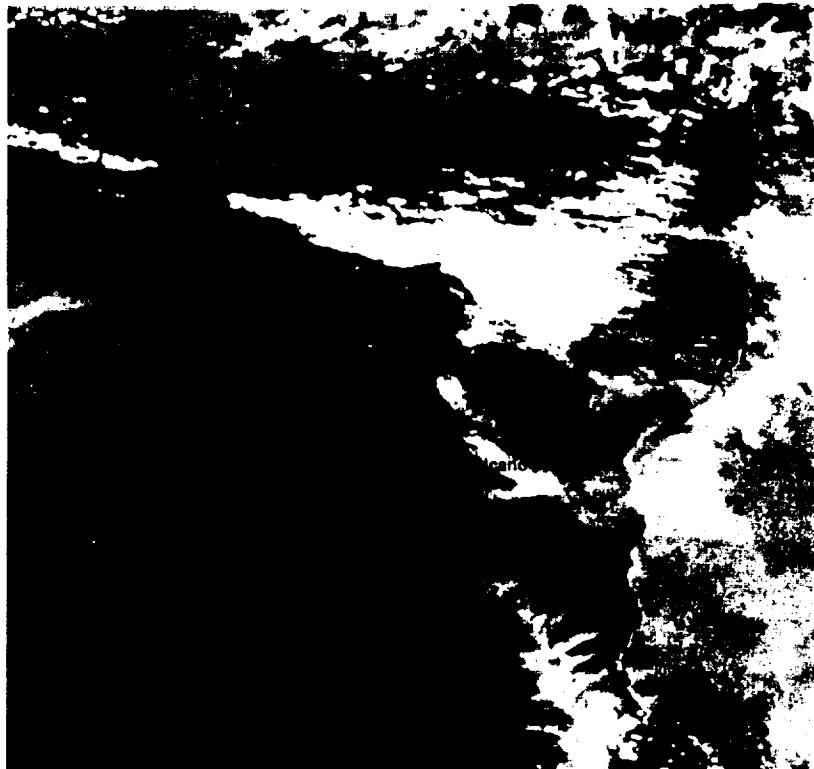
The Earth resources experiment program used a variety of scientific equipment to record data concerning Earth. These instruments, located in the docking adapter, surveyed Earth features and obtained photographs which provided valuable data to foresters, geologists, oceanographers, meteorologists, and others.

ography, mineral prospecting, and meteorology.

Agricultural studies benefited from mapping of soils; from inventories of crops; from the identification of soil moisture distribution parameters, soil and plant relationships, and possible underground water sources. Environmentalists profited from new knowledge of such areas as the rangeland ecosystem of Sierra-Lahorton and Colorado Plateau. Meteorologists and weather forecasters obtained valuable data from studies of the growth and termination of Hurricanes Ava, Christine, and

Della; and from the analyses of conditions preceding severe storms. Hydrologists were supplied much new information from Earth resources studies of major river drainage basins; and from groundwater resources inventories. Geologists obtained vast quantities of new data on surface morphologic and geologic features related to mineral deposits and from analyses of oil fields. Oceanographers made new discoveries from microwave measurements of sea state during calm and disturbed conditions; and from correlation of the chlorophyll content,





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A wide variety of terrain features was recorded by Skylab's cameras: (1) The colorful plateaus of southeastern Utah, (2) lofty Mount Rainier in Washington, (3) the wind-blown dunes of the Spanish Sahara Desert, and (4) volcanoes of the Hawaiian Isles were all studied by Skylab.

thermal patterns, and water mass variations with sportfish catches. And foresters were provided valuable data from studies of insect infestation of wooded lands.

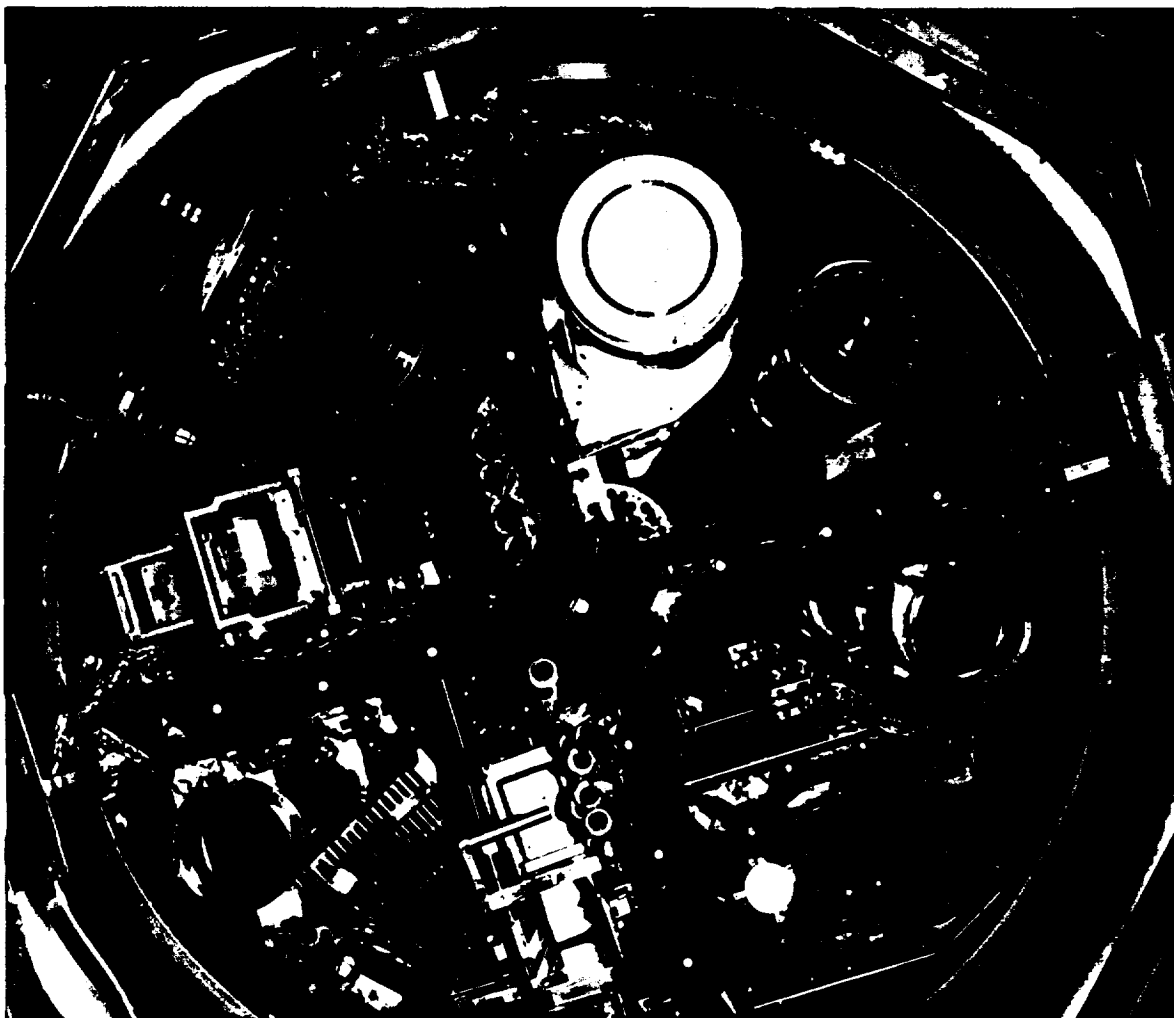
Other results of these valuable studies included the testing of the utility of such remote sensing for updating the 1970 census in 13 U.S. cities, the development of photomaps and the updating of some existing maps, and the successful demonstration of the use of space photography to map such remote regions as the "Green Hell" of Paraguay.

New Findings From Solar Observations

While Earth resources observations were being intensified, the solar observations begun by the first crew were continued, with many new developments.

With the exception of the H-alpha cameras, each instrument in the solar observatory made observations that could not be made from the ground. Similar instruments had been used previously on

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Eight highly sensitive instruments, mounted on the spar in the solar observatory canister, studied the Sun in great detail.

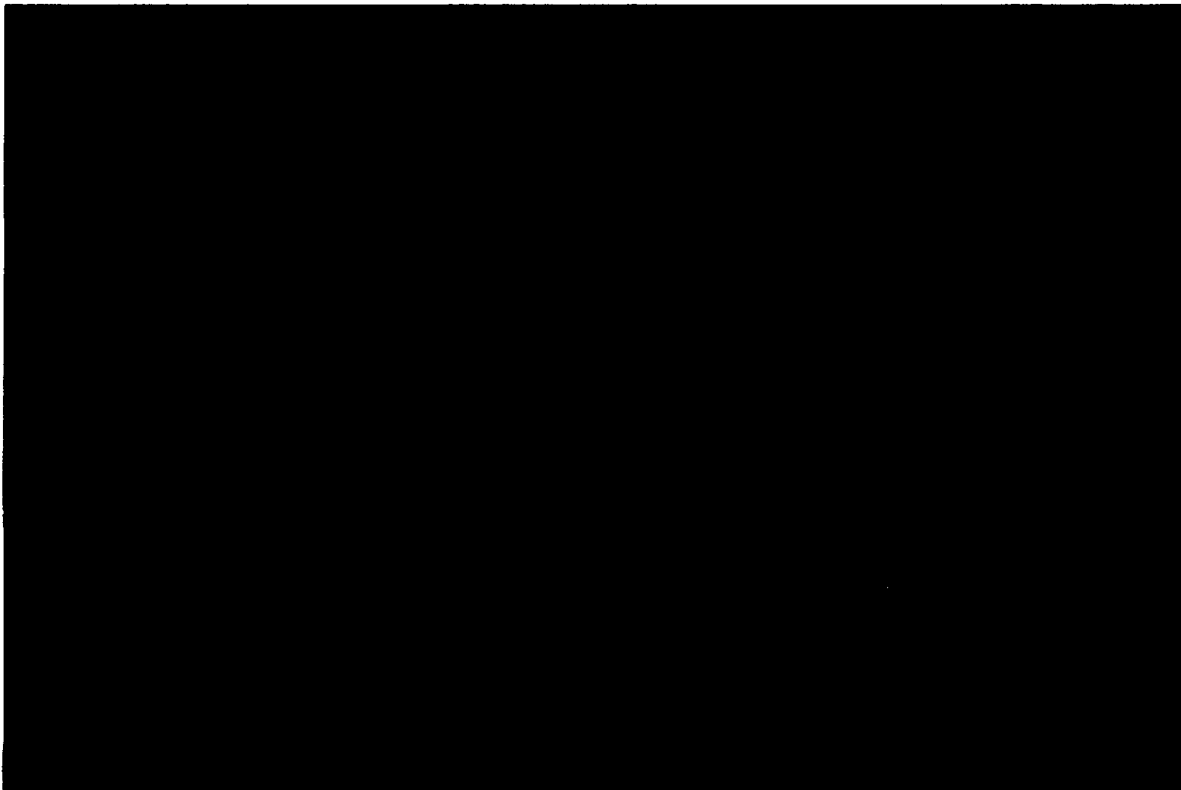
balloons, rockets, and satellites. However, the Skylab instruments were larger and more sophisticated, and they had more power at their disposal and greater data-taking capabilities than previous instruments.

During the second manned period, the astronauts obtained 77 600 telescopic images of the Sun's corona in the X-ray and ultraviolet and visible-light portions of the spectrum. They spent more than 300 hours conducting astronomical

observations. Most of the solar data were obtained when the Sun was high over the Earth's horizon to avoid interference from Earth's atmosphere. But some observations were made through the Earth's atmosphere to measure the constituents of the atmosphere.

Although the Sun was supposed to be in the relative quiet part of its 11-year cycle, it burst into extraordinary activity during much of the second manned period. This enabled the crew to obtain

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Typical of the photographs obtained by Skylab's solar instruments are these photographs of a solar eruption (top) and a solar prominence (bottom). (NAVAL RESEARCH LABORATORY)

significant data and photographs about the quiet Sun and photographs of an active Sun, including observations of some 100 solar flares.

Solar flares are massive outbursts of matter and energy from the surface of the Sun. On occasion, these flares arch back to different areas of the Sun and set off other flares. Scientists had long suspected this to be true, but had never before observed these phenomena to the extent made possible by Skylab.

Studies of the corona proved the existence of coronal holes, places in the Sun's corona which are cooler and more rarefied than the rest of the solar atmosphere. These holes extend downward to the chromosphere, the region where temperatures reach a minimum. From these coronal holes, observations showed that solar magnetic fields stretch outward rather than curving back to the Sun's surface. Scientists speculate that the holes may be the source of the solar wind, the hot electrified gas particles rushing outward from the Sun along magnetic lines of force.

Giant bubbles, often considerably larger than the Sun, were observed rising into the outer corona. Astronomers now believe that these bubbles may be responsible for magnetic storms on Earth.

Other observations resulted in additional findings. For example, solar bright points, discovered by Skylab, occur all over the Sun rather than just in the equatorial zone where most of the Sun's violent activities take place. Coronal transients, eruptions that frequently occur in connection with solar flares, reshape much of the corona, including its magnetic fields. And condensed streams of hot gas, called prominences, occur more frequently than astronomers expected.

Much of the success of Skylab's astronomical observations resulted from the continuous close contact between astronauts and ground crews. Professional astronomers manned the ground-support center throughout the entire manned period. They were supported by observatories all over the world, including a worldwide net of solar observation stations operated by the U.S. National Oceanic and Atmospheric Administration. Real-time data from the Skylab instruments were available to the astronauts, and some of these displays were transmitted to the ground. Voice communication links between Skylab and ground enabled ground crews to know what the astronauts

observed and the astronauts to know what ground observatories were able to see. Using these data, a group of astronomers, engineers, and experiment teams planned each day's observations and relayed instructions to the astronauts.

Even before Skylab was launched, a number of joint observation programs were developed, each structured to study one specific feature or activity on the solar disk, using as many of the Skylab astronomy instruments as possible. As the mission progressed, scientific teams selected the joint observation programs to be conducted each day. But the astronauts always had the option of modifying these programs based upon their real-time knowledge of solar activities.

Life Processes Studied Extensively

One of the principal objectives of the Skylab mission was to study life processes. Many of the experiments involved the flight crews, while others were performed with other life forms.

One of the star performers of the second manned period was a common Cross spider named Arabella. She and a sister spider named Anita had been brought aboard Skylab by the second crew to participate in an experiment suggested by a high school science student. The experiment was conducted to compare the web spinning capability of the spiders on Earth and in the zero-gravity environment. At first, Arabella had difficulty spinning her web, but when she became acclimated to the space environment, she spun webs closely resembling those she had spun on Earth. This prompted Scientist-Astronaut Garriott to observe, "It seems she learned very rapidly in zero g without the benefit of any previous experience."

Later, Anita was given her chance. Already adjusted to the zero-gravity environment, she spun normal webs almost immediately.

Additional experiments conducted with the Mummichog minnows provided intriguing results. Those brought aboard as minnows at first swam in tight loops. Those hatched from eggs that had been carried into space swam as they did on Earth.

The astronauts themselves were the subjects of a series of medical experiments to assess the effects of 59 days in space on their bodies. Medical tests made every 3 days showed that the astronauts' bodies were slowly changing, but not as quickly as did the first crew's. Since the second crew was



Arabella became a television celebrity when she spun an "earthly" web after becoming acclimated to the zero-gravity environment. Her first attempt, shortly after reaching orbit, showed a disorientation, but adjustment came quickly.

taking considerably more exercise, doctors attributed their lesser body change to this and continued to recommend at least an hour's exercise each day.

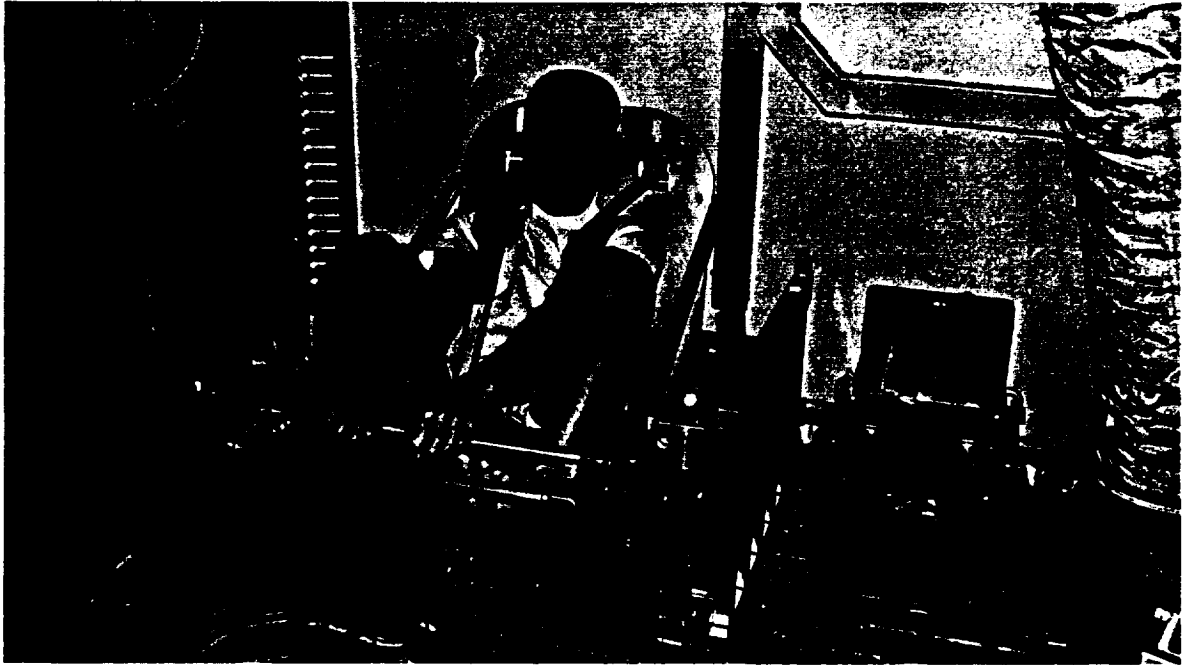
The space environment seemed to act as a stimulant. Bean, Garriott, and Lousma put in long days conducting scientific experiments, making observations, and taking photographs. They slept only 6 to 7 hours a day. Working at high efficiency, they requested additional assignments. They carried out each with relative ease.

By the 40th day, the gradual change in their physiological responses appeared to reach a plateau. This indicated that man has a capability to endure long-duration spaceflights.

Rate-Gyroscope Replacement Necessary

Meanwhile, Bean and his crew had to turn their attention to less glamorous, but still highly important, activities. A major problem involved the replacement in the system of six of the rate-gyroscope processors which were used to sense spacecraft attitude rates. There were three such rate gyroscopes for each of the three vehicle axes.

Within the first 21 hours after the initial launch, four of the rate-gyroscope processors overheated. Subsequently, two more showed identical symptoms. In addition, upon activating the Skylab control system, it quickly became apparent that many of the processors were behaving abnormally.



Here, Comdr. Alan Bean conducts tests to measure body mass in zero gravity.

Drift rates were 18 times higher than expected, which made it difficult to maintain the correct attitude for thermal control during the first 10 days after launch. But, as time passed, the drift rates decreased and eventually stabilized. Again, engineering teams on the ground were set to work analyzing the problem. They determined that the high drift rates were caused by gas bubbles forming in the gyro flotation fluid and were aggravated by the overheating of the gyroscope fluid caused by problems in an electronic control circuit. The design allowed the float-chamber bellows to be exposed to the hard vacuum of space thereby relieving the fluid pressure within the bellows and allowing entrained gas present in the fluid to form bubbles. Tests conducted to verify the theory of bubble formation showed that the theory was correct.

Available spare gyroscopes were modified on a crash basis. The vented bellows end cap was replaced by an unvented end cap so that internal float pressures would remain near the original pressure despite external pressure changes. The



Astronaut Carr keeps in shape using the exerciser on Skylab 4. The treadmill was assembled in space by the second crew and used throughout the rest of the mission.

overheating problem was also solved by modifying the mounting of some of the critical electronic components. Six such modified gyroscope processors, packaged in a "rate-gyroscope six-pack," were stowed aboard the command module and transported to Skylab by the second crew.

Installing this six-pack in Skylab required that cables outside the spacecraft be disconnected and reconnected during a spacewalk.

The second crew first installed the six-pack in the docking adapter near the control and display panel, on a mount previously provided for camera stowage. This location was close to the spacecraft center of gravity and was near a high-power outlet.

All three crewmen participated in connecting the six-pack. While Bean remained inside, Garriott and Lousma went into space to perform the very difficult task of disconnecting three cable connectors and installing the new cable and rate-gyroscope selector box, which required making four connections. Since this activity involved disconnecting the guidance system's main cable and making new connections, its successful execution was vital to continuing the mission. The astronauts were able to accomplish the task without incident, however, using special tools which had been supplied for this task.

Many Skylab systems were interdependent. Performance of one often depended upon proper operation of another. As one example, concern arose during the second manned period when the primary airlock coolant loop was shut down because of a suspected loss of coolant fluid. With only one coolant loop in operation during the period which would follow departure of the second crew, there would be no backup system available. A failure of this coolant loop would leave the laboratory power conditioners without coolant flow, which would require shutting down the batteries and electronic components in the power conditioners to insure their availability during the third manned period. The usual procedure would have been to open the battery and regulator outputs by ground command and allow the solar observatory to supply the total power until the third crew could resupply the coolant fluid. This operation, however, would have removed power from the workshop control bus, removing command capability from the system. Engineers decided that the proper way to power down in the event of a coolant flow loss was to leave the

regulator output relay closed, and reduce the regulator voltage. In this mode, the solar observatory would provide all of the power to the vehicle, effectively reducing the laboratory power output to zero. This would allow power to flow to the control bus through the regulator from the solar observatory. Because the regulator voltage could only be adjusted manually, that had to be done immediately before the crew's departure. This would have placed the entire electrical load on the solar observatory for the entire unmanned period to follow, which was undesirable. For that reason, the transfer relays were opened. The resultant 27 volts was sufficient to power the loads, and the transfer relays were left in the open position, with each system operating independently. If the coolant loop had failed, the transfer relays would have to be closed and the system would operate in the contingency mode. Fortunately, the secondary coolant system operated satisfactorily during the unmanned period, and the transfer relay was left open until after the arrival of the third crew.

At the end of the second manned period, the crew had performed well above expectations. Twenty-six Earth surveys had been scheduled; they performed 39. They had been scheduled to spend 206 hours in solar observation; instead, they spent 305, which resulted in 71 700 photographs of the Sun, a staggering bonanza of scientific data. In three extravehicular activities, they made necessary repairs and adjustments. They conducted extensive biomedical and life sciences experiments and proved beyond doubt man's capability to live and work in space.

An Unexpected Voice From Space

Throughout the manned period, they carried on continuous communication with ground personnel, working as a closely integrated team. Each problem was discussed in great detail, and the final solution was the result of agreement between engineers, scientists, and technicians on the ground and the highly trained Skylab crewmen.

But the ground crews were not prepared when, during the mission, a soft, unquestionably female voice called from space:

"Hello, Houston, this is Skylab. Are you reading me down there?"

There was an understandably long silence from Mission Control.

"Hello, Houston, are you reading Skylab?" the

voice called again. No mistake about it. It was clearly a woman's voice.

After another long pause, Mission Control replied, hesitantly, "Skylab, this is Houston. I heard you all right, but I had a little difficulty recognizing your voice. Who have we got on the line here?"

"Houston, Roger. I haven't talked with you for a while. Is that you down there, Bob? This is Helen here in Skylab. The boys hadn't had a home-cooked meal in so long, I thought I'd just bring one up. Over."

By this time, a crowd had gathered in Mission Control. Not quite sure what was going on, the controller replied:

"Roger, Skylab. I think somebody has got to be

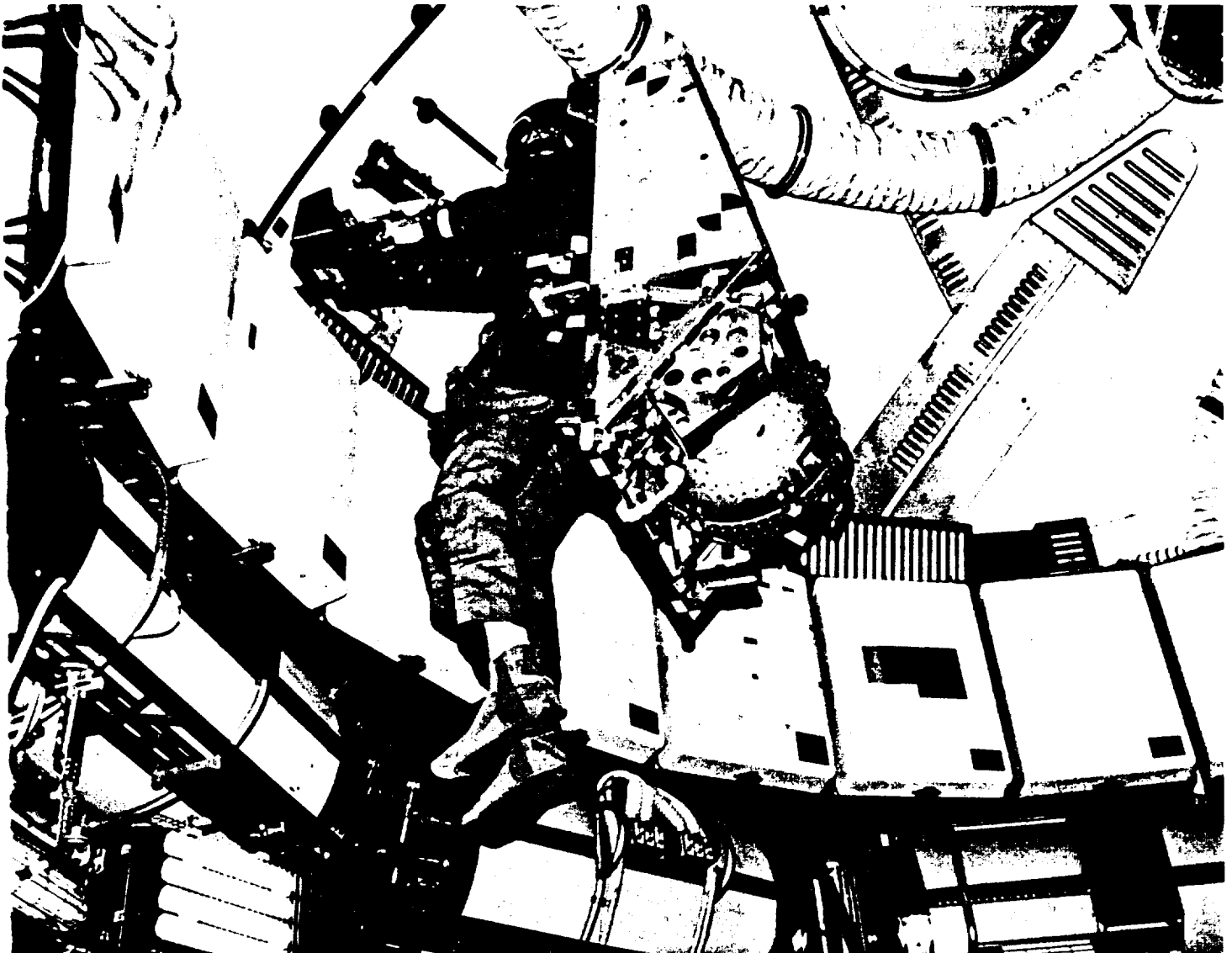
pulling my leg. Helen, is that really you? Where are you?"

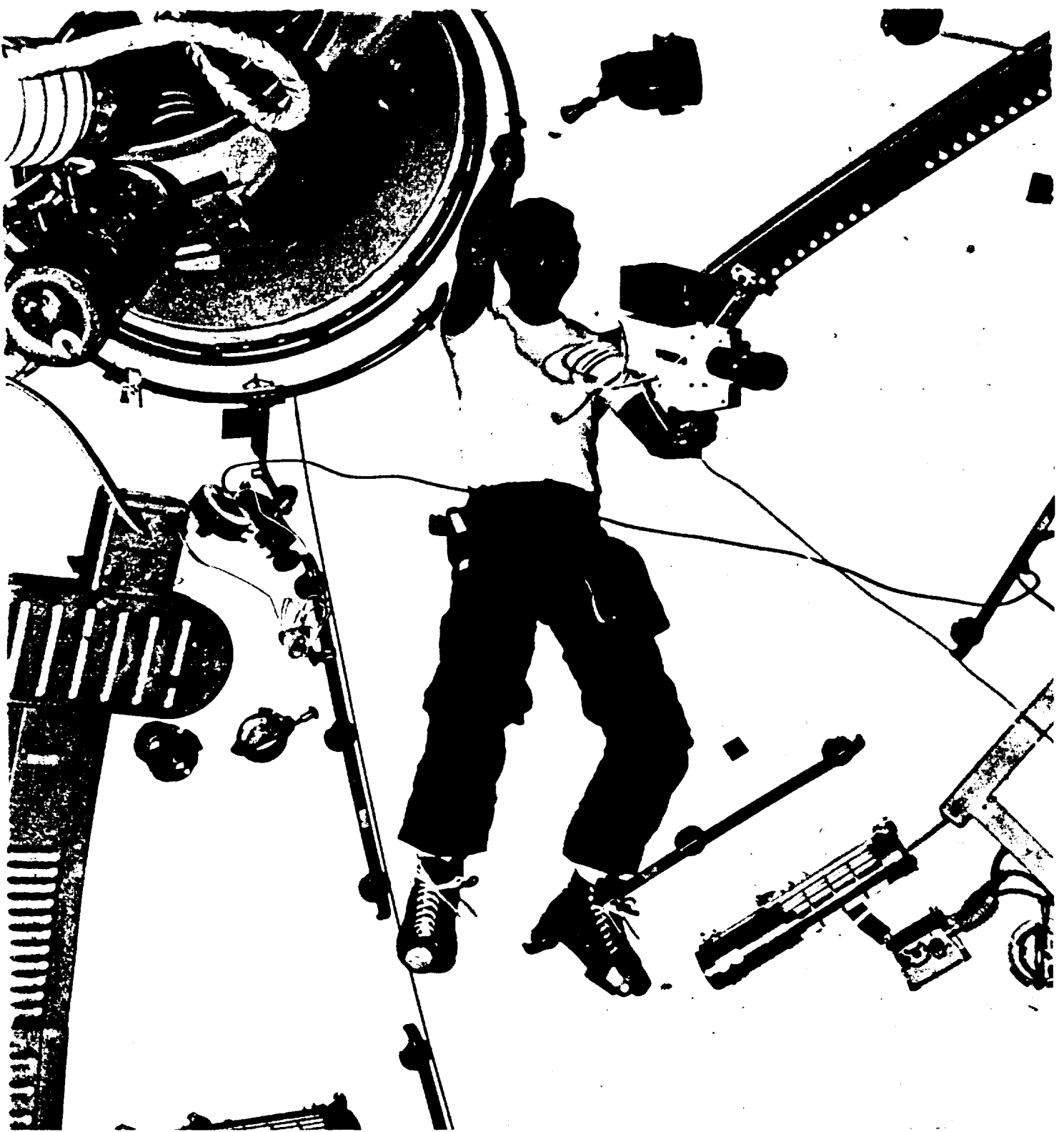
"Just a few orbits ago we were looking down on the forest fires in California. You know, the smoke sure does cover a lot of territory. And, oh, Bob, the sunrises are just beautiful."

Suddenly the feminine voice changed moods. "Oh, oh, I have to cut off now," she said. "I see the boys are floating up toward the command module, and I'm not supposed to be talking to you. See you later, Bob."

Still somewhat shaken by the event, the controller muttered, "Bye, bye," as the Skylab crew roared with laughter. Garriott had taped his wife's voice earlier and played it back at an opportune moment.

An astronaut maneuvering unit, shown here, was flown in the workshop to test it under weightless conditions for possible future application.





Garriott displays the lightweight portable television camera which the astronauts used to televise their activities.



As Skylab flight crews worked in orbit, engineers and technicians at Johnson's Mission Control Center and the Marshall Space Flight Center in Huntsville, monitored the consoles. They analyzed problems as they arose, performed tests as necessary, and relayed instructions to the flight crews for corrective action.

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Skylab, a Ground and Space Partnership

It was now obvious that man could live and work in space for very long periods of time, if he were given the proper support. So plans were changed. The third manned period would be extended to take advantage of this capability and to perform many more scientific experiments.

Although a number of technical difficulties had been experienced, each had been overcome by hard work and a spirit of cooperation and determination that characterized the entire Skylab effort. Much more had been accomplished by the first two crews than the planners had anticipated.

Earlier in 1973, a Czechoslovakian astronomer named Lubos Kohoutek, working with his telescope in Hamburg, West Germany, had discovered a new comet. According to his calculations, it would be quite near the Sun in December. Delay of the launch and extension of the manned period would permit the third crew to get a close look at this comet, and perhaps to make valuable observations of it.

Preparation for Third Manned Period

During the second manned period when an apparent leakage was detected in the coolant loop, the crew had examined the entire system very carefully, but could find no evidence of leakage. Nevertheless, the coolant pressure continued to drop slowly. So work continued in the technical laboratories to fabricate a kit by which the coolant

loop could be reserviced. The kit contained a tank and panel assembly filled with coolant, three short hoses and adapters, repair seals, and valves for connecting to the spacecraft coolant lines.

Two weeks before launch, one of the control-moment gyroscope's speed decreased slightly, while the current in one motor winding increased. But, after about an hour, the wheel speed and current returned to the normal reading. Although ground engineers did not know it at the time, this was an indication of a problem which was to threaten the third manned mission early in the period.

Unmanned solar observatory experiments continued to be performed as scheduled until just before launch of the third crew, when an orbital lock on the pointing control system failed to release. Observations were discontinued until the third manned period began.

At the beginning of the unmanned period, the workshop had again been depressurized to the 2 pounds per square inch level required to lower the dewpoint. Immediately thereafter, it was repressurized with nitrogen to 5 pounds per square inch to aid in cooling the six gyroscopes located in the docking adapter. This resulted in an imbalanced mixture of nitrogen and oxygen. Shortly before the third crew was to enter the workshop, the pressure was lowered to purge it of the unwelcome mixture and then repressurized with the prescribed mixture of nitrogen and oxygen.

Skylab's Scientific Mission Supported by Ground-Based Teams

Many of the experimental programs on Skylab were an extension of studies which had been underway on Earth for some time. Skylab added a new capability by which the results of many of these studies could be verified, or through which much new data could be obtained. Experimenters found in Skylab a means of comparing and correlating the results of Skylab experiments with data gained from ground-based observations. And they designed additional ground-based study programs to provide data in support of Skylab experiments.

Such ground-based supporting projects supplemented Skylab studies in several ways. By comparing ground observations and Skylab observations of the same object, an experiment could determine the kind and the degree of superiority which space observations might have over ground observations. By observing a given object, such as a group of sunspots, over an extended period of time before and after the Skylab mission, insight into evolutionary processes could be gained which would greatly enhance the value of Skylab observations. By observing at close range certain features of the Earth's surface, such as tectonic formations, ocean currents, or plant-growth patterns, a calibration table for the interpretation of Skylab pictures of the same features was established. Finally, in the case of biological and medical experiments, the ground-based observations enabled the investigator to isolate the effects of weightlessness on living organisms by comparing Skylab data with the results of observations under similar conditions on the ground.

The Skylab ground-based astronomy program was designed to obtain solar data from observatories around the world at the same time that the solar observatory instruments were viewing the Sun from orbit. Data gathered on the ground supported and supplemented the space-gathered data.

As a result of a request by NASA to solar astronomers for ground-based observations that would support and extend solar observations on Skylab, there were a number of agencies and companies which participated actively in the program. The University of Hawaii's Institute of Astronomy at Haleakala constructed a photometer for observations of active regions in the corona.

This instrument measured simultaneously the intensities of several visible coronal lines to determine the rates of energy loss and gain from the active regions and the effects of flare events on the corona. The Lockheed Missiles & Space Co. at Palo Alto, Calif., operated a spectroheliograph at the Kitt Peak's McMath Solar Observatory, which mapped physical parameters of the solar atmosphere. The California Institute of Technology installed a large photoheliograph at its observatory at Big Bear Lake, in California, a location where observing conditions are exceptionally good. Many others participated in this program, including the National Bureau of Standards, the University of California in San Diego, the Uttar Pradesh State Observatory in Naini Tal, India, and among others, the Applied Physics Laboratory of Johns Hopkins University in Baltimore.

The National Oceanic and Atmospheric Administration coordinated a solar data collection network among observatories in the United States and foreign countries. They also stationed representatives at Mission Control to provide NASA with real-time space environment data, analyses, and forecasts and to coordinate the operation of the solar data network.

"Ground truth" data became very important to the Skylab mission. Such data were obtained by direct observations on the ground of those areas, objects, and phenomena which were also being observed by Skylab. Nearly simultaneous observations were made of weather, lighting conditions, and other environmental factors which might influence the data gathered from Skylab. By comparing ground-truth observations with orbital observations of a particular test site, scientists were able to establish calibration factors which allowed the proper interpretation of orbital data from many sites.

Finally, NASA-operated and private aircraft were used to obtain data over the sites being observed by Skylab. These aircraft were equipped with a variety of cameras and imaging devices which generally approximated the capabilities of instruments aboard Skylab. Data acquired in this fashion were used to analyze and understand the space-acquired data.

Thus, while Skylab's crews operated scientific instruments, made observations, and conducted experiments, thousands of people all over the world worked in cooperation with them.



Astronaut William Pogue lifting the work chamber hatch at the materials processing facility.

Materials Processing Studies

Skylab offered a unique opportunity for materials processing specialists. Drop tower experiments had proved that the elimination of the influence of gravity profoundly affected some materials processes. Some limited experiments conducted on Apollo flights verified these early results, so when the opportunity for more elaborate and better controlled experiments on Skylab arose, experimenters prepared an extensive program to study the processing of materials under prolonged weightlessness. Melting and mixing without the contaminating effects of containers, the suppression of thermal convection and buoyancy in fluids, and the ability to take advantage of electrostatic

and magnetic forces and otherwise masked by gravitation opened the way to new knowledge of material properties and processes. Ultimately this beginning will lead to the production of valuable new materials for use on Earth.

The materials processing facility developed for Skylab accommodated 14 different experiments carried out during the three manned periods. The facility, located in the docking adapter, contained a spherical work chamber that could be evacuated by opening a vent toward space, a 1.6-kilowatt electron beam gun for intense local heating, and a furnace for the uniform heating, or heating with a temperature gradient, of samples in three separate cartridges. The flight crews operated the facility by selecting the experiment, loading the experiment

into the furnace, and applying the desired heating. After cooling, the samples were stowed for return to Earth where detailed analyses were performed by the experimenters.

Each of the experiments demonstrated some decisive influence of gravity upon processes that are essential in the formation of materials.

Simulators Considered To Be Valuable Tools

Innovation and improvisation characterized the Skylab mission. But this was often the result of extensive training under simulated space conditions.

A number of simulators were used before and during the mission for procedures development, problem analysis, crew training, and other functions. These proved extremely valuable to the success of the mission, especially with the problems related to loss of the micrometeoroid shield.

The Skylab simulator proved to be a very valuable device in which the crewmen familiarized themselves with workshop operating systems. It was especially useful in learning to operate the solar observatory and in understanding the attitude control system, since these systems were operated in orbit by the flight crews. The simulator was designed so that one crewman could operate the control system while the other crewman operated the other workshop systems and the solar observatory. Failures in the control system were then introduced, and the system was operated while the solar observatory was kept pointing at the Sun.

The neutral buoyancy simulator was a very effective training device. Through its use, the crews developed the skills and procedures needed for extravehicular activity. The second crew reported that, "Once basic extravehicular activity skills are acquired in the water tank, a crewman can perform extravehicular activity tasks for which he is not specifically trained if adequately detailed instructions are given. The techniques and skills developed underwater are almost identical to those used during the extravehicular activity, with the actual zero-g task being slightly easier."

Full-scale simulated flight components were always used for practicing extravehicular activity procedures underwater.

The crew further stated: "Underwater simulations and training are not needed for tasks to be performed inside the spacecraft, unless the crew-

man will be performing the tasks in a pressurized suit. Anything that can be done on Earth in a 1-g environment in shirtsleeves can be accomplished in zero-g. A slightly different body position may be required in zero-g."

Other simulators were used for training in use of the Earth resources experiment package, in stowage procedures for the command module, in rendezvous and entry procedures, and in familiarization with Skylab's operating systems.

Thus, simulators were valuable tools for training flight crews. But they were also extremely valuable to engineers and technicians supporting Skylab when troubles occurred.

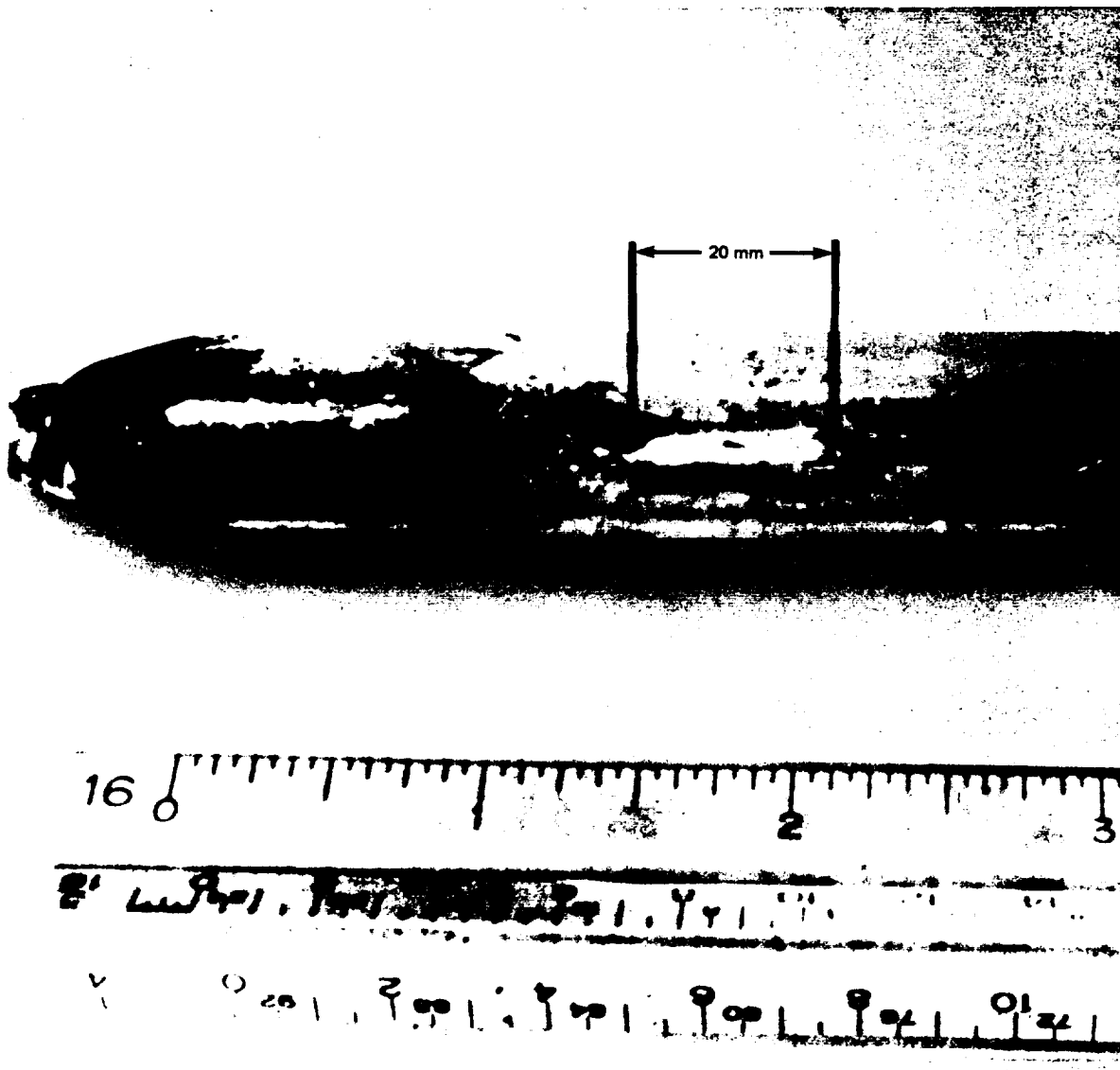
A simulator which reproduced the workshop instrumentation and communications systems, located in St. Louis, and a test unit and a solar observatory instrumentation and communications simulator located at the Marshall Space Flight Center were used to reproduce problems in that system and develop means for correcting them.

Simulators were also used to support analysis of the Skylab electrical power system. A computer program simulated electrical system performance over a wide range of operating conditions and environments. This program was used each day during the mission to analyze proposed attitudes of the space station. It was especially valuable during the first 10 days of the mission. Throughout the mission, however, it proved its value in power management.

Many simulators were used in the design and verification of the attitude and pointing control system. Such simulators ranged from those which were computer models of the overall system to those employing full-size system components. One such model, used extensively late in the mission, simulated thruster bursts for given maneuvers and recorded the quantity of nitrogen gas used. With the aid of this model, engineers planned thruster use to keep gas consumption to a minimum.

The glamour of manned spaceflight has often overshadowed the enormous amount of work done by ground crews during the flight and by the many engineers and technicians at the NASA centers, aerospace contractor plants, universities, and by other groups in preparation for these flights.

Skylab demonstrated dramatically the great contribution to mission success made by those thousands on Earth who supported the flight crews throughout each manned period and who kept

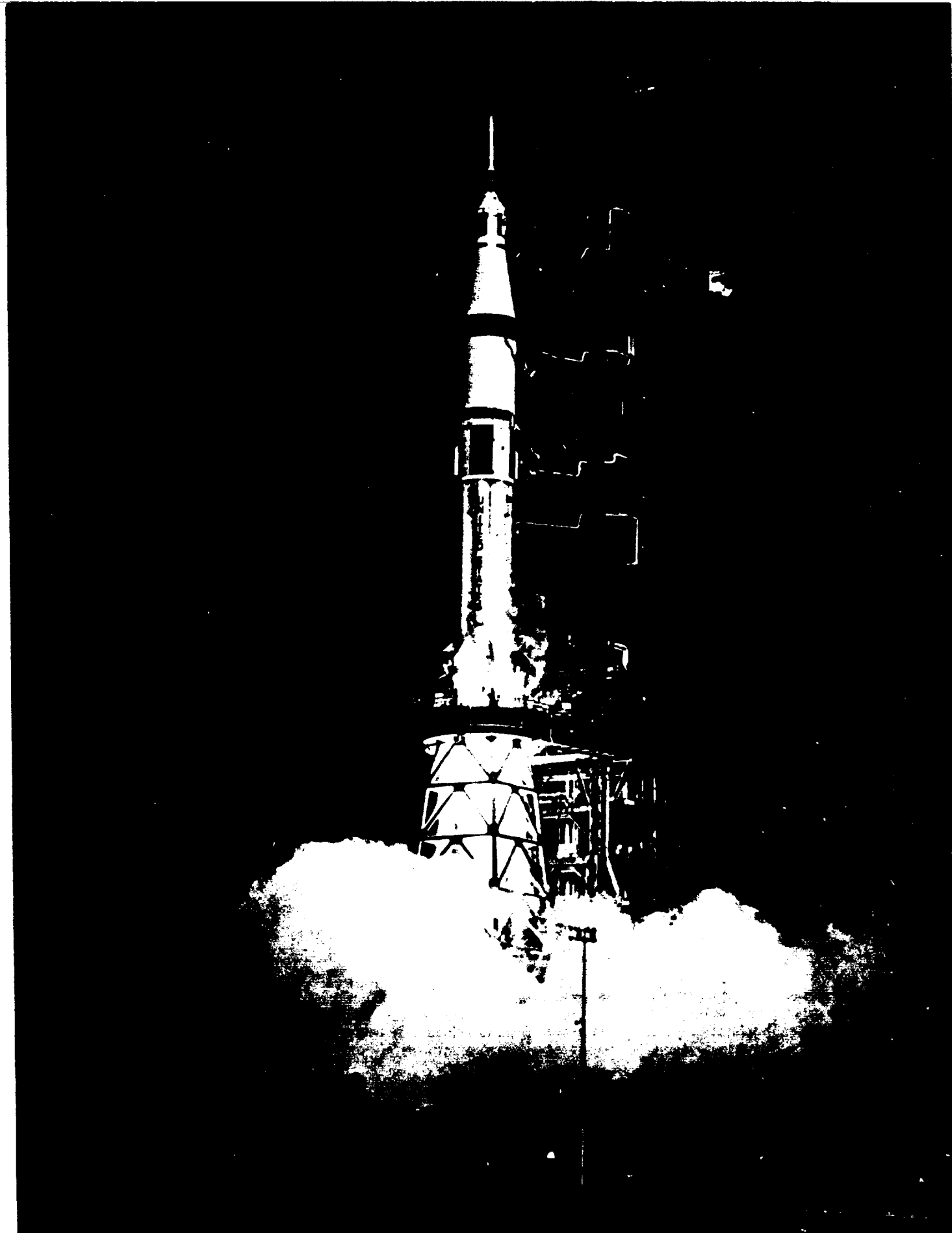


Among the numerous experiments conducted in materials processing was the growth of crystals, such as this semiconductor crystal of germanium selenide.

Skylab operating properly during the periods in which it was unoccupied.

Thousands of interdependent tasks had to be performed correctly and on time for the mission to succeed. Countless hours of preparation went into the execution of each task, and thousands of

people, each working at his own specialty, made up a team whose spirit of dedication and cooperation assured success. Skylab was a team effort, and no one was more aware of this than the third flight crew which was being prepared for man's longest voyage into space.



9

The Third Manned Period

Encouraged by the accomplishments of the first two manned periods, and especially the adaptability of the second crew to long periods in the weightless environment, NASA decided to extend the third manned period to 84 days, if crew and space station conditions would permit. In addition, many tasks were added for the crew to perform during its scheduled 12 weeks in space.

Preparations for Launch

Even before the flight began, trouble arose.

Ground crews, making routine preflight inspections of the Saturn launch vehicle, discovered hairline cracks in the bases of the rocket's eight huge stabilizing fins. The cracks were small, but ground-support engineers took no chances. New fins were installed.

During another check, technicians discovered similar cracks in seven of eight support beams in the structure connecting the first and second stages of the rocket. They "beefed up" the beams with heavy aluminum plates.

Then, two of the launch vehicle fuel tanks buckled slightly while fuel was being drained. This was soon corrected by refueling the tanks under pressure, which forced the dome-shaped tops back into shape. Metallurgists inspected the tanks and ruled that they were safe for launch.

On the morning of November 16, 1973, everything was in readiness for the launch. Strapped into the astronauts' couches in the Apollo command

and service module was a rookie crew, soon to set new space records. Although neither Gerald Carr, Edward Gibson, nor William Pogue had ever flown in space, each had compiled a wealth of experience in preparation for the venture.

The command module was loaded with supplies and additional equipment needed for the third crew's lengthy mission. It also carried additional items needed for reservicing or replacing equipment, replacing items with improved designs, providing for changes in planned activities, replenishing supplies because of higher-than-planned usage rates, replacing lost items, providing additional crew comfort, and providing for improvements in communications, television transmission, and photography. And additional food for the longer mission—some 160 pounds—was aboard, along with replacement film and new cameras. To make extra room, engineers had removed the vibration padding which normally was used for packing equipment and had replaced it with clothing.

The Third Manned Period Begins

Seven hours after launch, Carr and his crew spotted the Skylab.

"She looks pretty as a picture," Carr called out. Expertly, he maneuvered the command and service module to join Skylab, and a short while later, the two craft were docked.

Because the previous crew had experienced motion sickness early in their manned period, Carr

and his fellow astronauts took preventive medication. Ironically, Pogue, a former member of the Thunderbirds, the Air Force aerobatic team, became ill. The crew spent the first sleep period in the command module. Both Pogue and Carr experienced symptoms resembling motion sickness during the first 3 days in space, but this soon passed.

The crew also had problems during activation of the workshop that earlier crews had not faced. One of its first tasks was to unload and stow within the spacecraft thousands of items needed for their lengthy manned period. The schedule for the

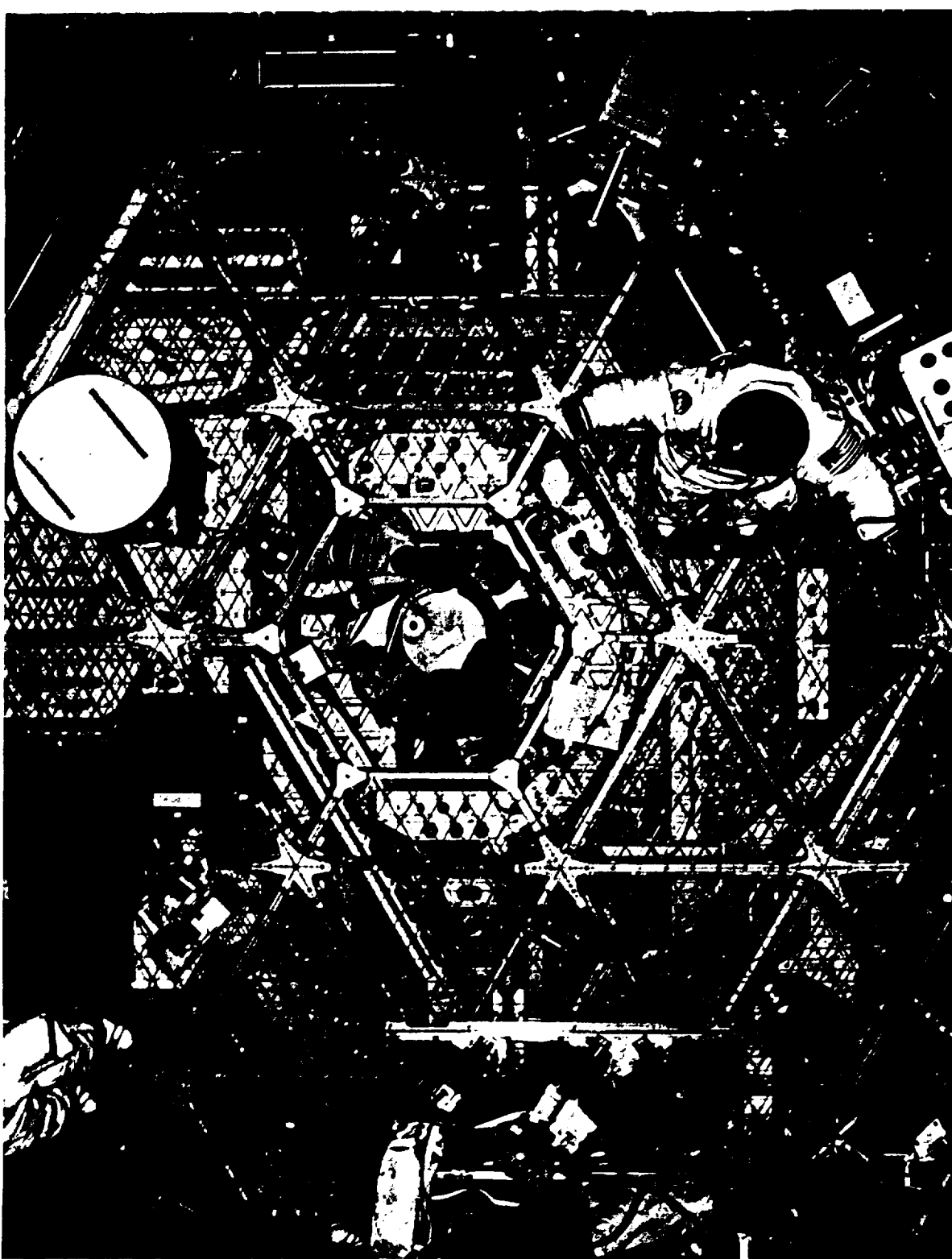
activation sequence dictated lengthy work periods with a large variety of tasks to be performed. The crew soon found themselves tired and behind schedule.

As the activation period progressed, the astronauts complained of being pushed too hard. Ground crews disagreed; they felt that the flight crew was not working long enough or hard enough.

In the last weeks preceding the third manned period, many tasks had been added without additional time for training of the crewmen to execute them. New medical tests, new scientific experiments, and extra equipment and supplies which

Skylab's third crew, Astronauts Gibson, Carr, and Pogue, talk about the mission during training. They were to remain in space for 84 days.





Here, Gibson and Carr peer through the octagonal opening which separated the workshop's two levels. Behind them is the trash airlock.

had to be stowed, all contributed to a feeling on the part of the crew of being overwhelmed. In addition, the crew found that many of the items in the workshop used previously were not where they had expected them to be.

Struggling to keep up with the heavy workload, the crew made errors on several experiments. The astronauts found that lack of training on some of their new medical experiments was frustrating. "We've never seen some of these before," they complained.

Faced with a problem of lagging schedules and mistakes, ground and flight crews resorted to a time-honored means of resolving the problem: they talked, openly and frankly. Work schedules were adjusted, and the crew was given more time to relax. Both crew performance and communication with Mission Control improved almost immediately. And by the end of the manned period, the third crew had completed even more work than had been planned.

Commander Carr summed up the crew's feelings in a discussion with ground-support crews: "A guy needs some quiet time to just unwind if we're going to keep him healthy and alert up here. There are two tonics for our morale—having time to look out the window and the attitude you guys take and your cheery words."

Thanksgiving in Outer Space

Thanksgiving Day, Gibson and Pogue spent 6½ hours in extravehicular activity. The first part of their spacewalk was devoted to replacing film in the solar observatory. The remainder of the time was used to repair a malfunctioning antenna. Utilized to view the Earth as a part of the Earth resources experiment package, the antenna was mounted outside the Skylab on the airlock truss.

During the second manned period, antenna motion had become erratic. Ground engineers determined that the condition was most probably caused by a short in the electronic device controlling either pitch or roll. They developed a procedure to isolate the problem and correct it, and fabricated a repair kit, which included a jumper box for isolation of the short, a tool pouch with appropriate repair tools, and astronaut restraints for use during the extravehicular activity. Prior to flight, the third flight crew carefully rehearsed the repair procedure in the neutral buoyancy tank.

Using the checklist they had developed during simulated operations, Gibson and Pogue shared the work outside. Carr remained in Skylab guiding their operations, performing fault isolation, and making sure that Gibson and Pogue followed the prescribed routine.

Removing three flight cable connections and installing the jumper box, Pogue tested the circuit while Gibson held his feet and steadied him. A malfunction test showed that the trouble was a short in the pitch axis only. The procedure then called for them to remove a linchpin and install a manual gimbal lock.

To free the launch lock, they had to tap it several times. This two-man operation required aligning holes in the pitch gimbal housing with a hole in the pitch gimbal shaft by rotating the antenna and locking it in that position, then putting a disabling plug on the launch lock circuit.

With their chores completed and the antenna functioning, they sat down to an ample Thanksgiving dinner. Carr selected prime rib for his main course, and Pogue chose chicken and gravy. Gibson adhered to tradition; he ate turkey and gravy.

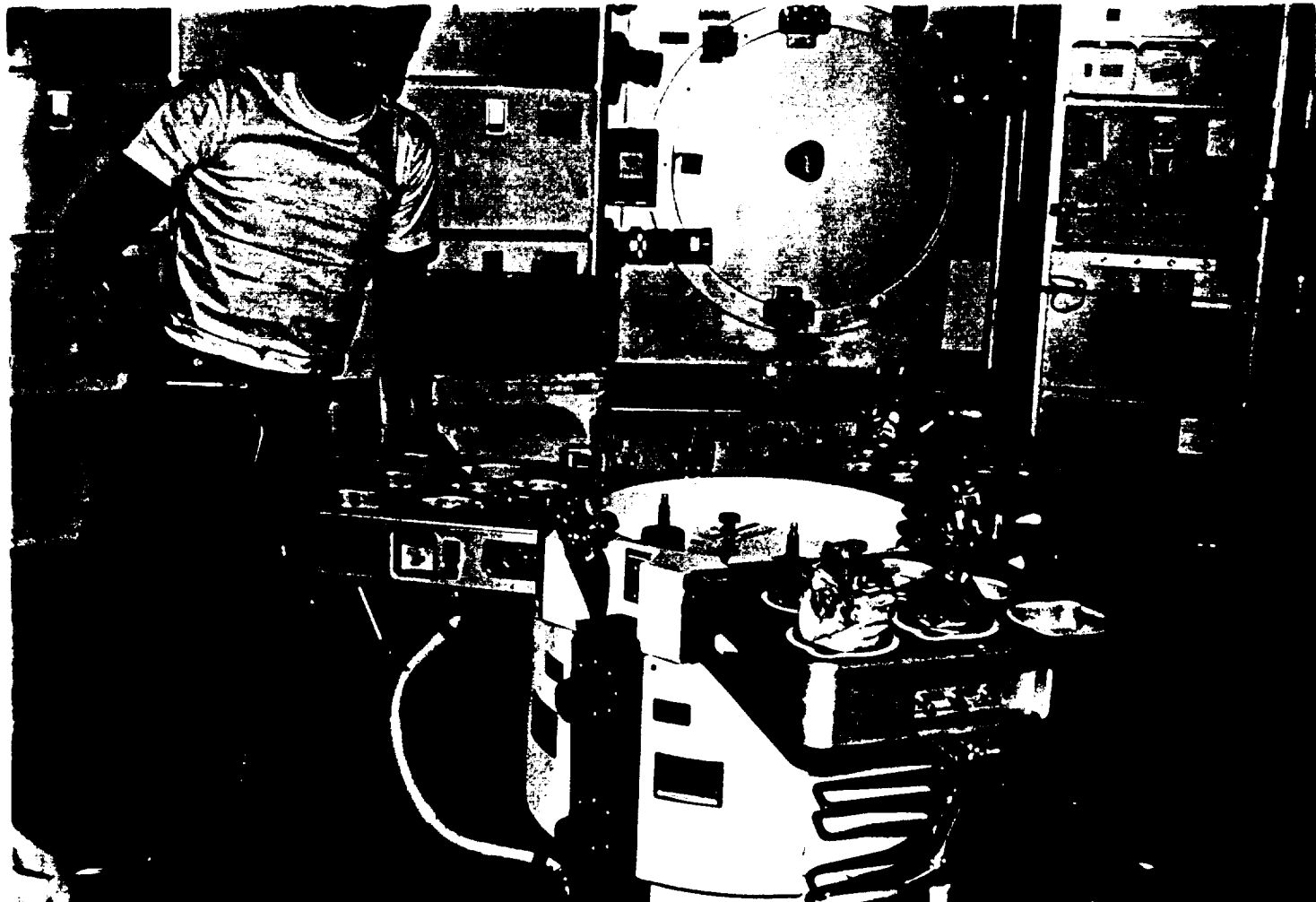
As earlier crews had done, the third crew reported that the food was very good, but slightly bland. Although condiments usually enhanced the taste, the crews could not use them as much as they would have preferred. The amount of salt they could use, for example, was restricted for medical purposes. And the quantity and type of food consumed was rigidly controlled because of their strict diet.

The crew found that they could not go as long without eating in zero gravity as on Earth, especially during the early part of the mission. They became hungry faster and felt the adverse effects of hunger more quickly.

Generally, they found the packaging of the foods very good. But some of the packages made of material with elastic properties sometimes catapulted bits of food into the laboratory.

Problems With the Control-Moment Gyroscope

Seven days into the manned period, a serious problem developed in the control-moment gyroscope system, which threatened early termination of the mission. This system was the principal means of maneuvering and controlling the attitude of the space station. The thruster attitude control



Gibson in the crew wardroom. Space meals were ready to eat. The third crew ate Thanksgiving dinner at this food table.

system had been used often during Skylab's initial 10 days. As a result, its propellant had been depleted to the extent that it could not be depended upon to control the Skylab attitude throughout the remainder of the third manned period. Consequently, any problem in the control-moment gyroscopes was very serious.

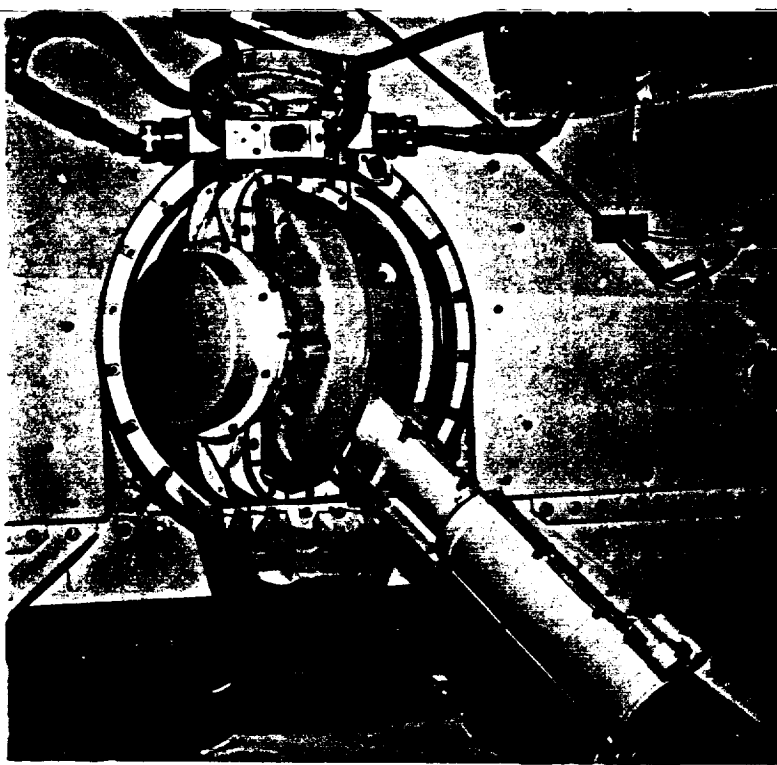
The system depended upon three large gyroscopes, sized so that any two of them could provide sufficient torque to control and maneuver Skylab as desired. The third added to the control capability and acted as a backup in the event of failure of one of the others.

As Skylab neared contact with the Bermuda tracking station, ground observers noted a severe rise in the bearing temperature of one of the gyroscopes. At the same time, they saw a decrease

in wheel speed and an increase in wheel spin motor current. As soon as they detected the irregularity, ground control shut down this gyroscope and the computer automatically switched to two-gyroscope control.

The failure of this gyroscope was attributed to insufficient lubrication. Somewhat later in the period, a second gyroscope gave similar indications, but special temperature control and load reduction procedures kept the second one operating, and no further problems occurred.

The star tracker continued to give problems as it had during the first and second manned periods. The most frequent problem experienced with it was its tracking of contaminant particles which entered its field of view. If such a particle reflected light with sufficient intensity, the particle was



The star tracker was an important part of the attitude and pointing control system. It measured attitude in roll and provided star position data for experiment pointing. As the third manned period progressed, the star tracker continued to malfunction and finally became unusable.

tracked as a target star. Contaminant particles, generated by the sloughing of paint, dust, outgassing, or venting from Skylab, often distracted the star tracker.

During the second manned period, the shutter of the sensor had stuck in the open position on five occasions. This was attributed to mechanical binding of the shutter drive mechanism. On each occasion, the shutter would recover, usually within several hours. But bright light from the Earth's albedo apparently reached the photomultiplier tube while the shutter was open, degrading the tube response and lowering its sensitivity. As a result, one target star, Alpha Crux, could no longer be tracked. The astronauts selected the star Rigel Kent as an alternate and tracked it successfully.

Halfway through the third manned period, the star tracker malfunctioned once more, and far more seriously. Failure of its outer gimbal position encoder rendered the star tracker useless, and it was lost for the remainder of the mission. After this time, ground crews computed equivalent information from telemetered data. The crew then used a sextant to measure star positions.

Crew Alerted by Warning Signals

Problems which developed aboard Skylab were usually detected immediately, either by the crew or by ground-support engineers through a caution and warning system which provided visual displays and audio warnings when problems developed.

This system monitored selected functional systems characteristics, and alerted the crew to imminent hazards or out-of-limit conditions which could result in jeopardizing the crew, compromising mission objectives, or losing a critical subsystem. Characteristics monitored were categorized as either emergency, warning, or caution. When any of the characteristics reached predetermined out-of-tolerance level, appropriate visual and acoustical alarms were set off.

The emergency category included any condition which could cause crew injury or threat to life and which required immediate corrective action, including predetermined crew response.

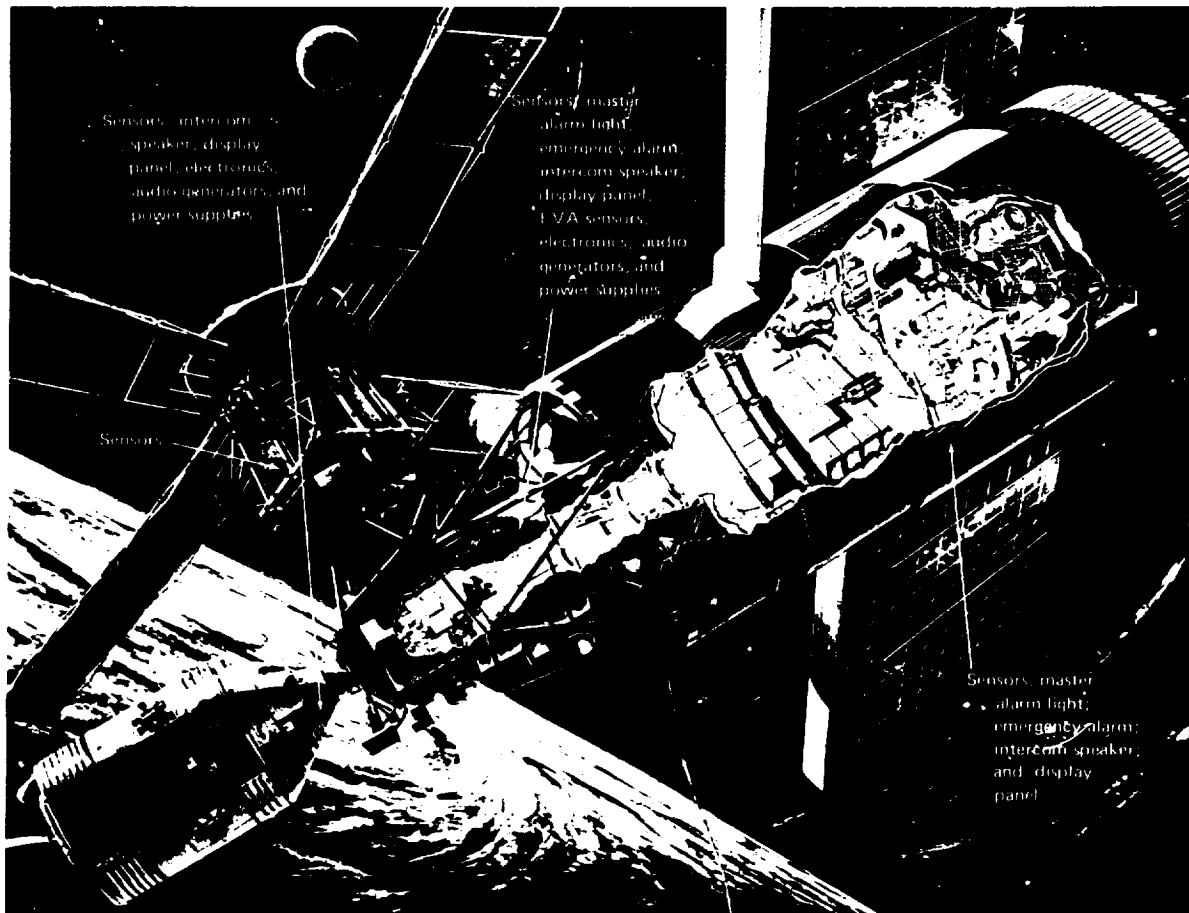
The warning category included any condition or malfunction of a Skylab system that would adversely affect crew safety or compromise mission objectives and which required immediate action by the crew. The caution category included any out-of-limit condition or malfunction of a Skylab system that affected primary mission objectives or could result in loss of a system if not responded to in time, and which required crew action, although not immediately.

Twenty-two fire sensors were located throughout the pressurized compartments of the space station. Each consisted of an ultraviolet detector and a quick-release adapter plate for ease of replacement. There were 2 fire sensors in the docking adapter, 8 in the airlock, and 12 in the workshop. Each sensor was a self-contained unit with a 120-degree field of view. A fire signal from any of the sensors resulted in the generation of emergency alarms.

Other sensors in Skylab detected rapid losses in pressure. A pressure decrease within the space station of 0.1 pound per square inch per minute, or greater, would have immediately set off an emergency alarm.

Signals set off by these sensors were converted into audio tones—a siren for fire and a loud buzzer for rapid loss of pressure.

The caution and warning system monitored 76 system characteristics including flow rates, volt-



Caution and warning system

ages, and coolant temperatures. Thus, a serious malfunction was detected immediately, and corrective action could be taken promptly.

Most of the alerts during the first mission resulted from recycle of a system function; troubleshooting, attempted repair, or "workarounds," by the crew or the ground; or when the crew went outside the space station, and the hatch was initially opened. These alarms were all expected.

The system operated normally throughout the Skylab mission, successfully monitoring all 76 system characteristics. Some of the 220 system alerts were false alarms, however, all of which were associated with fire sensors. These false fire alarms

were attributed to high temperatures associated with the loss of the meteoroid shield prior to deployment of the thermal parasol, high radiation levels as the Skylab passed through the South Atlantic anomaly, and exposure to ultraviolet radiation which entered the vehicle as direct sunlight or as reflected light.

Repairs Reflected Ingenuity

Skylab's third crew made repairs to correct some problems that had developed earlier. Much of their maintenance activity was similar in nature to that carried out by homeowners to retain necessary appliances and household fixtures in operating

condition, but involved much more sophisticated equipment. The astronauts replaced the solar observatory television monitor in the control and display panel, repaired the laboratory tape recorders, replaced an electronic unit in the videotape recorder, and replaced a defective seal in the washcloth squeezer.

One of the repair jobs performed by the third crew had been anticipated in advance and a special kit prepared to service the leaking primary airlock coolant loop—the same problem that had been identified during the second mission.

Since these coolant loops had not been designed for onboard servicing, repair required innovation. Ground crews had to find a means of reservicing the loops, develop the necessary equipment and tools, and test them.

The solution was indicative of the ingenuity displayed consistently by ground-support engineers and flight crews. The procedure called for stripping insulation from a coolant line in the airlock, piercing the line with a saddle valve assembly which had a quick-disconnect attachment for attaching a service hose, and forcing coolant into the line from a small storage tank.

The third crew had taken the necessary parts and tools with them in the command module. The saddle valve fitted over the coolant line and provided a tight seal so that when the built-in cutter pierced the line, no coolant could escape. With the valve open, the crewman forced coolant into the line by applying pressure to a bellows in the supply tank. After sufficient fluid had been added to it, the primary loop was reactivated. It operated satisfactorily for the remainder of the mission, and no further addition of coolant was necessary.

Life in Zero-Gravity Environment

Once over their initial bout with motion sickness and with their work schedule problems resolved, the crew found their environment stimulating.

"There is very definitely an adjustment period at the beginning of orbital operations," they observed. They compared it to the period of adaptation one experiences when he moves from a sea-level environment to a high-altitude environment, or vice versa, except that the physiological changes involved are accentuated when going to zero gravity. They found that there was a definite

degradation in personal physical reserves or stamina while the body tries to make its adjustment.

Exercise was essential during the spaceflight, and the hour and a half exercise period each day kept the crewmen in excellent physical condition. Each crewman reported feeling better after heavy exercise.

They used a variety of exercise devices. The bicycle ergometer was exceptionally good for cardiovascular, pulmonary, and large leg-muscle conditioning. The Mark I exerciser, a floor-mounted unit with a rope and handle, was used for stressing the upper torso and arms. A treadmill device was especially beneficial for conditioning the calves and putting a heavy compression load on the total skeleton, particularly the spine, feet, ankles, and knee joints. Walking, running, and toe-rise exercises maintained the smaller muscle groups necessary for balance.

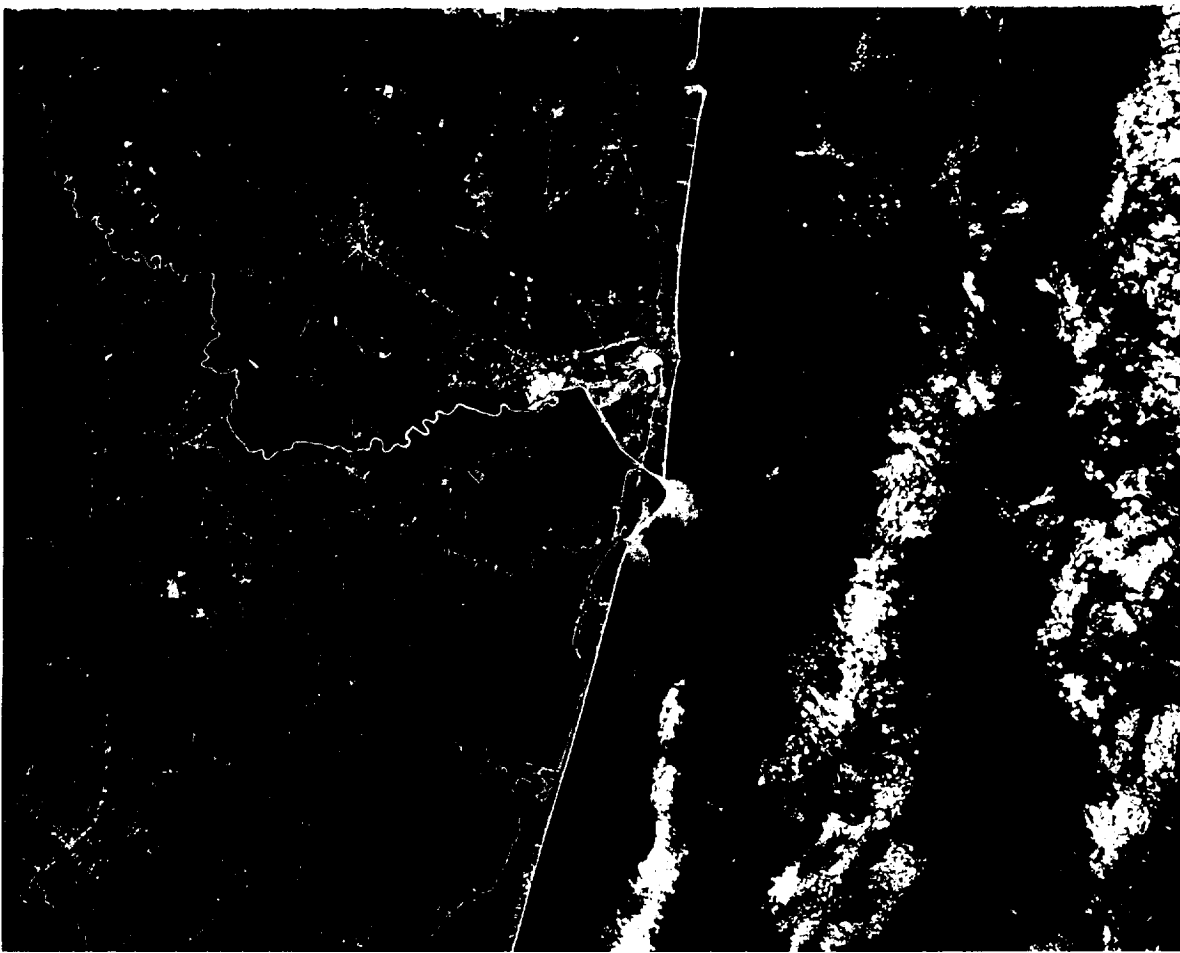
As the manned period progressed, the astronauts each grew an inch or more in height, and became slimmer, the result of stretching of the vertebrae in the absence of gravity and from the shifting of body fluids from the lower to the upper extremities. Shortly after their return to Earth, they resumed their earthly size.

The crew was in good health and high spirits as Christmas neared. On Christmas Eve, their families gathered in Mission Control, and the crew trained their television cameras on a tree they had fashioned from food containers. Christmas messages were relayed from ground to orbit by means of the teleprinter. In the messages were clues sent by their families which sent them on a search through the space station for presents from their wives.

A Long Look at the Blue Planet

Like the two crews before them, the third crew spent many hours looking at the Earth. Carr and Pogue alternately manned the controls, operating the sensing devices which measured and photographed selected features on the Earth's surface. And, when not otherwise occupied, they watched through the workshop window as the Earth rolled steadily beneath them.

In the 12 weeks they spent in orbit, the crew watched in fascination as vegetation changed color with the seasons, as busy rivers froze and lay



Heavy concentrations of silt pour into the Gulf of Mexico from the San Bernard and Brazos Rivers, as shown in this Skylab photograph of the Texas Gulf coast.

dormant in winter's icy grip, as puffy clouds floated away to reveal vast expanses of the planet they called home.

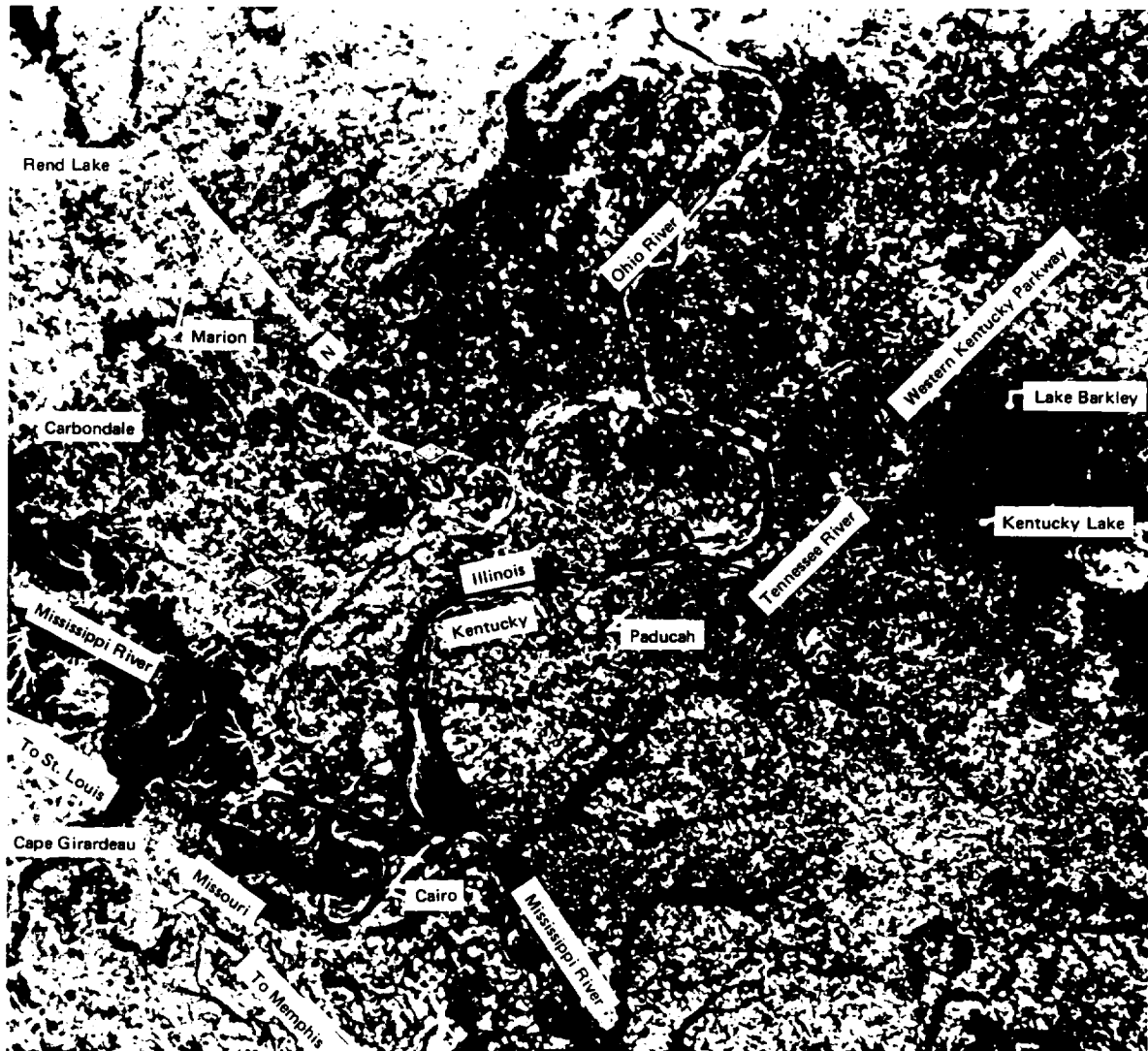
One awed astronaut could only exclaim, "Holy cow!" as he watched the lights of Acapulco, Guadalajara, and then Mexico City brilliantly greet them through the clear, cold December sky. Then, as they passed over the Texas coast, they could see clearly from Brownsville to Port Arthur, then New Orleans and, finally, the entire eastern United States, with lights aglow from the Great Lakes to the Gulf. "It's like a spider web with water droplets on it," Carr said.

The crew expressed delight in the opportunity to watch the Earth below them. Much of its appeal, they said, rested in the fact that they were permitted to exercise their judgment in selecting sites and times for observation. In contrast, they

expressed dissatisfaction with not being allowed the same flexibility for observations with the Earth resources experiment. Using hand-held cameras, they photographed many features of their own choosing, gathering some 20 000 photographs and recorded data on 19 miles of magnetic tape.

Oceanographers, in close communication with the flight crews, followed their observations of the shimmering light-green Falkland Current and concluded that they were watching a vast river of plankton. The crew reported swirling pools, believed to be cold water, in the warm Gulf Stream that runs from the Caribbean along the southeast U.S. coast, and then eastward to Europe.

From their orbital vantage point, the astronauts recorded the scars left by strip mining, studied the sandy wastes of the Sahara and Gobi Deserts, and assessed potential new energy sources.



This infrared photograph taken with a Skylab Earth resources camera graphically depicts the terrain at the confluence of the Mississippi and the Ohio Rivers.

Patience a Virtue in Solar Observation

Solar observations continued, with about 75 000 new telescopic images of the Sun recorded, in virtually all its phases. Images taken in the X-ray, ultraviolet, and visible portions of the spectrum added vast new knowledge about our most impor-

tant celestial body. The new data strengthened the conviction that the solar corona is more dynamic and complex than astronomers had previously believed.

Throughout all three manned periods, the crews eagerly watched for signs of a solar flare. There is as yet no way to predict when a flare will occur,

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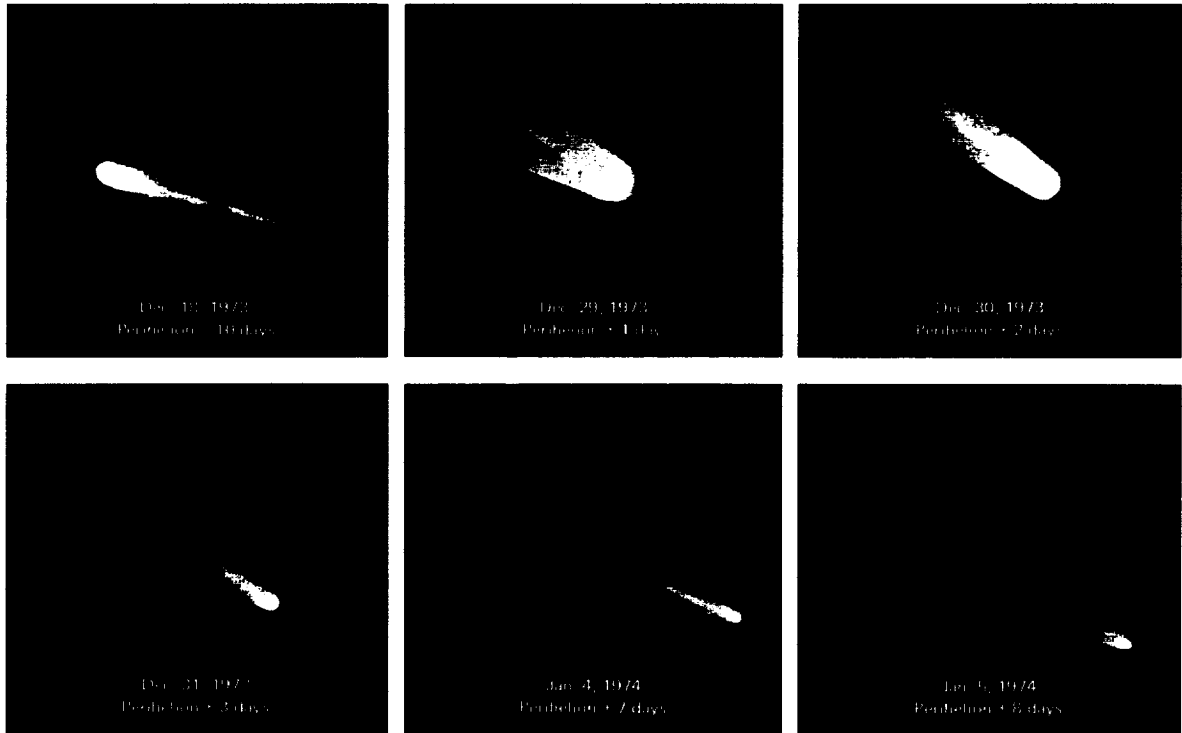
and scientists were eager to study the processes that take place as the flare is born. It is then that the transfer from magnetic energy into heat energy takes place. Unlocking the secret of this energy transfer, some scientists believe, might offer a way to obtain inexpensive energy for use on Earth.

As the end of the manned period drew near,

Gibson continued his patient watch of the solar surface. Day after day, he sat before the monitors of the solar observatory console, watching and waiting. Then, on January 21, an active region on the Sun's surface gave birth to a bright spot which intensified and grew. Gibson quickly began filming the sequence, as the bright spot erupted. His

Comet Kohoutek's hydrogen halo is clearly evident in the far-ultraviolet camera photograph taken from Skylab on Christmas Day, 1973.





Comet Kohoutek from astronaut sketches and descriptions.

patience had been rewarded. He had filmed the birth of a solar flare from space, the first such recording in history.

Comet Kohoutek

Following the discovery of the Comet Kohoutek, scientists prepared an electronographic camera with image converter tube, which was the backup camera used on the Moon by the astronauts of Apollo 16. The third crew took it with them in the command module. This camera could be operated either from inside the workshop, through the scientific airlock with its articulated mirror, or on the outside during extravehicular activities of the crew.

On December 13, the crew sighted Kohoutek and trained the solar observatory and hand-held cameras on it. They continued to photograph it as it approached the Sun. And on December 30, as it swept out from behind the Sun, Carr and Gibson spotted it as they were performing an extravehic-

ular activity. "It looks yellow and orange, just like a flame," Carr remarked. "Mostly yellow," said Gibson, who described it as "one of the most beautiful sights in creation I've ever seen."

Goodbye to an Orbiting Home

"It's been a good home," Gibson observed, as the Apollo module carefully maneuvered away from the Skylab. "I hate to think we're the last guys to use it."

Astronaut Robert L. Crippen, in Mission Control, asked the flight crew to "say goodbye for us. She's been a good bird."

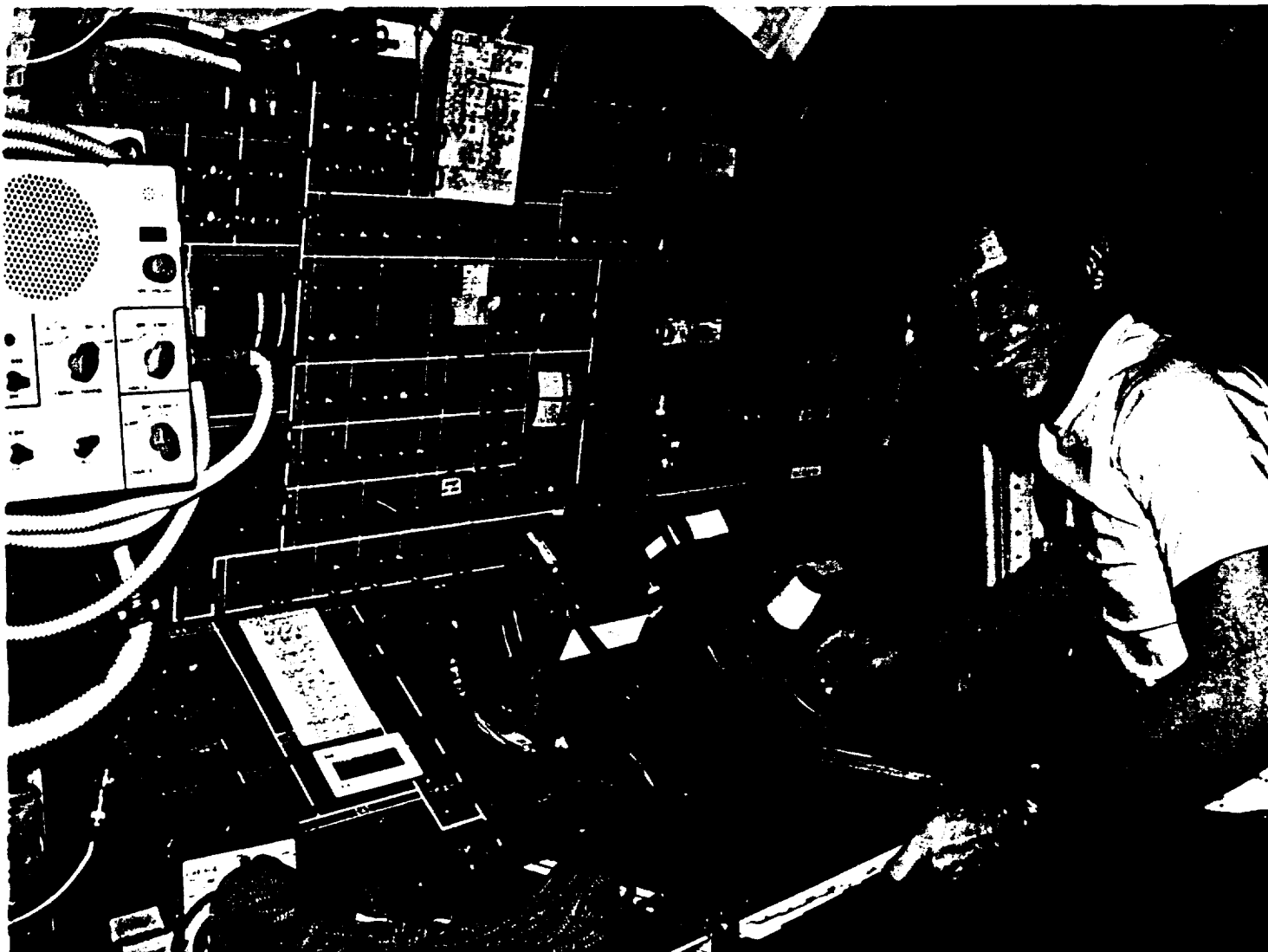
In spite of difficulties which seemed at times almost insurmountable, Skylab had met or exceeded every requirement placed on it. Every phase of the work planned—solar observations, Earth studies, student experiments, materials processing, medical tests—had resulted in spectacular success. The three flight crews had spent 171 days 13 hours and 14 minutes in orbit, had made a total of 2476

revolutions of the Earth and had traveled 70 500 000 miles in space. They had spent 41 hours and 46 minutes outside their spacecraft in extravehicular activity, had recorded 182 842 observations of the Sun and had made 40 286 photographs of Earth.

James C. Fletcher, NASA's Administrator, said,

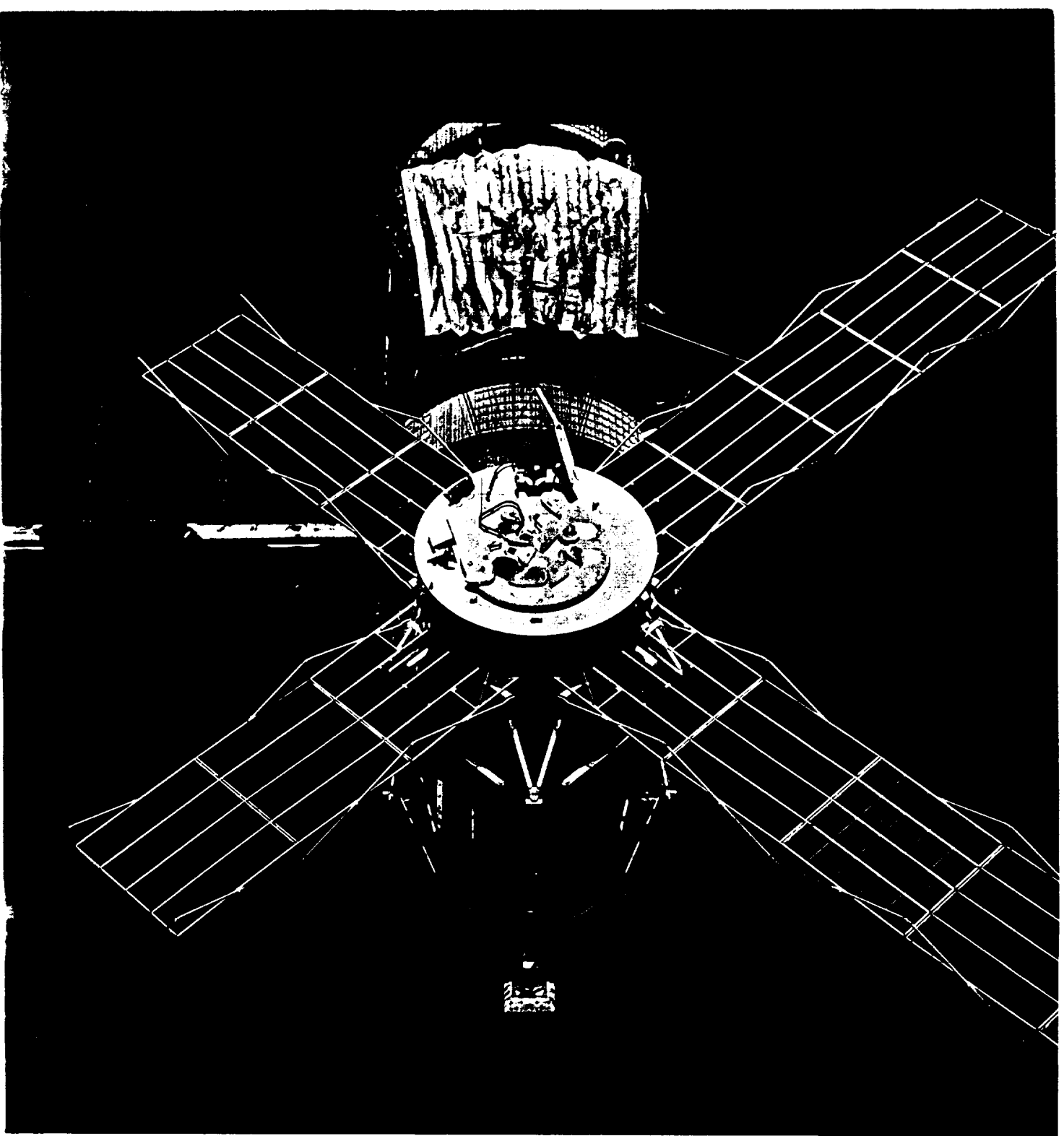
"We will be living with Skylab's achievements for a long, long time." With the vast amount of data collected or transmitted to Earth by instruments aboard Skylab or through crew participation, scientists will be many years completing their studies.

Scientist Pilot Gibson watched the Sun at this control console for hours on end, and eventually succeeded in photographing the birth of a solar flare.





Daily housekeeping involved the stowage of biologically active trash, such as food cans and urine waste, in the waste tank. Here, Carr opens the trash airlock through which bagged trash will be passed into the waste tank.



As the third crew departed the space station, a smiling Skylab seemed to wink "goodby."

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The Legacy of Skylab

With Skylab's flight activities completed, emphasis shifted to reducing and interpreting the vast amount of data collected. This task will continue for several years, both because of the great amount of data collected and the need to correlate it with other data obtained simultaneously through observations made by Earth-based scientific teams.

The multidisciplinary scientific program involved over 100 experiments devoted to observations of the Sun, studies in stellar astronomy, medical experiments to study man's adaptability to long-duration zero-gravity exposure, studies of Earth resources, materials processing, and the conduct of a series of scientific experiments proposed by high school science students. The results of this program constitute a legacy to mankind, the value of which will increase as evaluation of the data produced by the program continues.

Man's Adaptability to Long-Duration Spaceflights

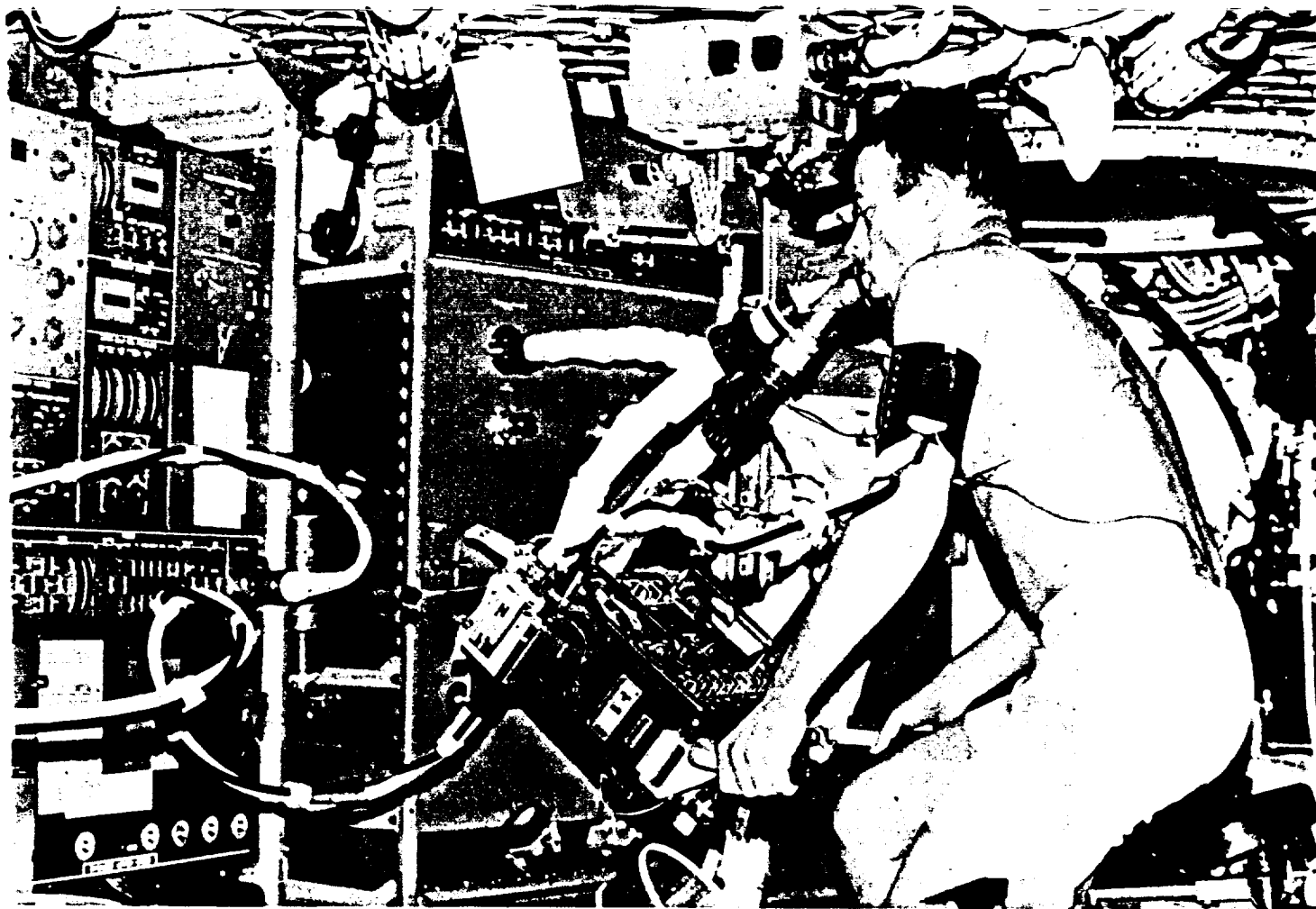
Since the earliest days of the manned spaceflight program, there had been a continuing concern expressed regarding man's ability to live and operate efficiently during extended spaceflights. Previous studies of man exposed to zero gravity observed a consistent loss of body fluid; a small, but repeated loss in bone calcium and muscle mass; and a reduction in the ability of blood vessels to actively distribute blood to the various parts of the

body following return to an Earth gravity condition. These effects always disappeared a few days after the astronauts' return to Earth and showed no consistent correlation with the time spent in space. Interestingly, similar effects have been observed in individuals confined to prolonged bed rest on Earth.

The Skylab biomedical program was a study of normal, healthy men and their reactions to an environment in which the influence of gravity was absent. Skylab, with its three, increasingly longer, manned periods, provided an excellent opportunity for the study of the importance of gravity to man's physiological functions. It provided a means for evaluating medical phenomena under prolonged zero-gravity conditions using rigorous evaluation techniques. Moreover, it provided an opportunity to evaluate psychological effects of prolonged periods of weightlessness, an important consideration if even longer manned spaceflights are to be undertaken.

Studies and investigations undertaken included: the effect of gravity on nutritional requirements and the attendant gain or loss of the body's biochemical constituents; the role of gravity in man's metabolic effectiveness in doing mechanical work; the effects of long exposure to zero gravity on the heart and blood vessels and measurement of the response of the circulatory system to various workloads; the behavior of the blood cells, body fluid compartments, body immunity, and the like when gravity is absent. They also included the role

Throughout the three manned periods, the medically trained astronauts conducted frequent and thorough examinations of each other, to assure their continued good health. All flight crewmen remained in excellent health throughout.



Astronauts Weitz (above) and Conrad (left) use the bicycle ergometer for metabolic activity experiments and exercise.



of gravity on man's psychomotor efficiency and the performance of useful tasks; the responses of the human vestibular system in the absence of gravity; the influence of zero-gravity environment and the more rapid day/night cycles on the normal human rhythms of sleep and wakefulness.

All 16 of the biomedical experiments were carried out, and man's adaptation to zero gravity was obtained for the first time. Medical experts have essentially agreed that man can, indeed, function effectively for long periods of time in zero gravity and then return to Earth without experiencing adverse effects. Joe Kerwin, a doctor of medicine, and a commander in the Naval Medical Corps, stated: "It was a continuous and pleasant surprise to me to find out how easy it was to live in zero g, and how good we felt."

Throughout the Skylab mission, crewmen found

the environment of weightlessness thoroughly stimulating. They were able to work long days without tiring excessively, and they worked with an efficiency that far exceeded expectations. They did find that their new environment demanded that they take much more exercise than required on Earth. And exercise in space required some interesting adjustments. For example, the design of the bicycle braking system created the requirement for the astronaut to deliver a forceful upstroke. To remain seated firmly as they exercised, they used an arm restraint and sometimes placed a pad between the top of their heads and the ceiling.

Surprising Results From Vestibular Function Tests

The purpose of the human vestibular (inner ear) function test was to examine the effect of weightlessness on man's sensitivity and susceptibility to motion and rotation, and his perception of orientation. Tests before, during, and after the flights were carried out in a chair that was rotated by a motor at its base while the crewman being tested performed nodding and sidewise head movements until he approached a feeling of stomach uneasiness. An attempt was made to reach the same level of symptoms in each test.

In ground tests conducted before each flight, crewmen rotated at between 10 and 20 revolutions per minute and executed 50 to 75 head movements before experiencing stomach awareness. In the zero-gravity environment, however, crewmen rotated at the maximum rate of 30 revolutions per minute and carried out 150 head movements with few or no symptoms of illness. After returning to Earth, they retained this apparent immunity to motion sensitivity for several weeks.

Tests of cardiovascular (blood circulating) response and exercise tolerance were usually conducted sequentially. A characteristic of cardiovascular deconditioning is the partial failure of reflexes in the venous blood vessels resulting in excessive pooling of the blood in the legs when standing erect in a gravity field. When excessive pooling takes place, the rate of blood flow through the heart and lungs is reduced, causing a reduction in pulse pressure, elevation of pulse rate, and eventual reduction of the average pressure. This results in a reduced flow of blood to the brain and other tissues, and it often results in dizziness or fainting.

Tests of the cardiovascular system in zero gravity were conducted in a lower body negative pressure experiment. The crewman, instrumented to record his blood pressure, vectorcardiogram, and calf circumference measurements, was sealed up to his waist in a cylinder. A partial vacuum was then drawn on his lower limbs and torso, producing blood pooling in his legs. The pressure reduction was such that it challenged the cardiovascular system in a manner comparable to the man standing erect on Earth. Following this test, the crewman moved to the bicycle ergometer for a carefully prescribed program of exercise.

The lower body negative pressure experiment became a significant challenge in orbit, although it had never been a problem on Earth. This was apparently the result of reduced total blood volume in orbit and pooling in the legs during the periods of negative pressure. Some tests were terminated before reaching the desired pressure reduction, because of the approach of fainting.

With one exception, manual coordination functions posed no problem. Reaching or handling objects was entirely normal, as long as visual contact could be maintained. However, in the sleep compartment, with all the lights out, crewmen found it almost impossible to reach out and touch the light switch located less than 2 feet away.

"The result was not just a near miss," according to Owen Garriott, "we found that our hands might first encounter a locker as much as 45 degrees away from the correct direction. Although I tried to 'practice' this move on a number of occasions, I still could not do it well after 2 months."

All crewmen reported that there were no psychological problems associated with the lack of clearly established "vertical" or "horizontal" orientations. Crewmen easily adjusted their impression of "up" to conform to body orientation. This capability was evidenced repeatedly as the flight crews performed repairs and carried out experiments with increasing effectiveness as the mission progressed.

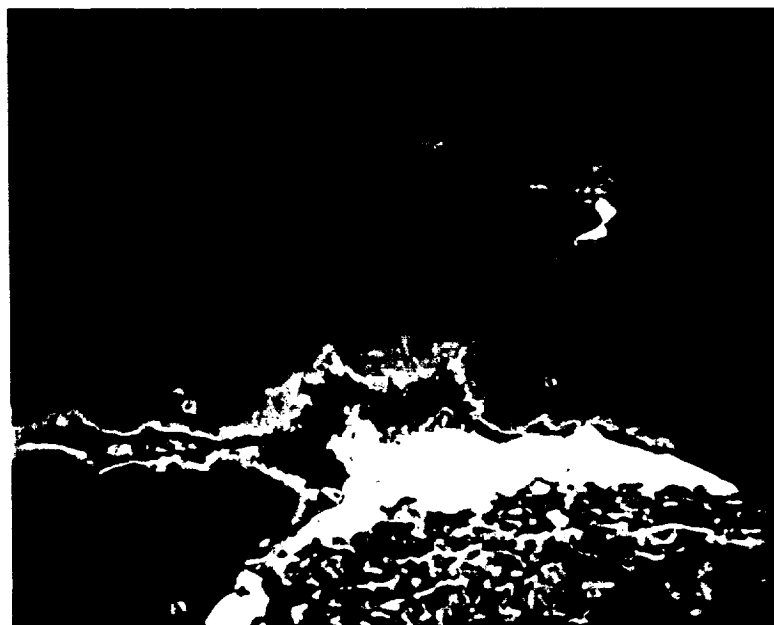
One of the more intriguing results of the program was the change in outlook, "almost of a spiritual nature," of the crewmen, observations which had also been expressed by earlier space explorers.

In the view of Edward Gibson, "Being up here and being able to see the stars and look back at the Earth and see your own Sun as a star makes



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you . . . realize the universe is quite big, and just the number of possible combinations . . . which can create life enters your mind and makes it seem much more likely."

And Bill Pogue commented, "I now have a new orientation . . . of almost a spiritual nature. My attitude toward life and toward my family is going to change. When I see people, I try to see them as operating human beings and try to fit myself into a human situation instead of trying to operate like a machine."

A Detailed Study of the Sun

As an observing station in orbit, well above the constraining influence of the Earth's atmosphere, Skylab attracted the interest of astronomers and space physicists from the time it was first conceived.

The Sun is the center of the solar system. Its radiations and emissions affect everything within that system, from planets such as Earth and Mars to comets and spacecraft. Its atmosphere extends out into space in a steady stream called solar wind and engulfs the entire solar system. It is a giant laboratory in space in which physical processes can be studied on a scale not producible in an Earth laboratory. Many discoveries have resulted from studying the Sun, including the lightweight element helium. Many of the high-energy processes of modern astrophysics have counterparts on the Sun where they can be studied in sufficient detail to arrive at an understanding of the mechanisms involved. The Sun serves as a testbed of the theory of gravitation, because it has the strongest gravitational pull of any celestial object near enough for detailed study.

Riddles presented by the Sun include its loss of mass, through the solar wind, radiations, and perhaps even dust; its spin-down through solar wind drag; its failure to produce the nuclear reaction products called "neutrinos," which could confirm or disprove the theory of nuclear energy production in its interior; its temperature structure with a 10 000°F inner atmosphere supporting an outer atmosphere of millions of degrees; the mysterious structures in its atmosphere including sunspots, polar regions, and streamers.

Three of the many photographs taken by Skylab's solar cameras that have provided revealing detail about the Sun.

The flow of solar energy is not steady. Some solar emissions are highly energetic and can cause important effects on Earth, including the interruption of shortwave radio communication, scrambled telegraphic messages, and other phenomena.

Solar flares set off magnetic storms which cause many curious effects. For example, oil exploration teams making electromagnetic measurements deep in wells find their highly sensitive electrical instrumentation inoperable due to interference from magnetic storms. Commercial power systems have been blacked out by high-voltage surges caused by magnetic storms.

There is also increasing evidence leading meteorologists to conclude that solar activity profoundly influences our weather and climate.

Skylab's orbiting solar observatory was designed for the conduct of unique experiments and observations which would help man advance his knowledge about the Sun and the myriad greater and lesser stars beyond.

Dividends From the Solar Observation Program

The solar observatory, with its eight high-precision instruments, was operated principally from the control console in the docking adapter by an astronaut who directly initiated instrument observing sequences. During periods when the astronauts were on board but not present at the console, limited operation of several of the instruments was possible by ground command. In addition, three instruments could be operated from the ground during the unmanned periods.

The Sun was supposedly in the quiet period of its 11-year cycle. But solar observations quickly revealed that even during its quiet phase, it was extremely active, as evidenced by the appearance, frequency, and distortions produced by large transients in the corona. Large "magnetic loops" observed by Skylab's telescopes expanded through the corona at a velocity of 900 000 miles per hour. During planning for the Skylab mission, astronomers had expressed the hope that transient events of some sort might be observed on two or three occasions; over 60 events of this type were seen, usually associated with eruptive prominences in the chromosphere. After a major transient, the coronal structure was completely altered within the volume of the event and a new structure was formed which persisted for weeks or longer.

Observations of the Sun's lower corona and the



The southern aurora, luminous bands of light in the southern hemisphere, was photographed from Skylab. The space station was moving into the sunlight when this photograph was taken. The view is near the edge of the auroral cap, with the surface of the Earth in the foreground.

chromosphere revealed dramatic details of this extremely active region between the dense photosphere and the very tenuous outer corona. X-ray photographs of the Sun showed numerous "bright spots," with diameters of about 600 miles and lifetimes of only a few hours. Other X-ray studies showed "coronal holes," from which X-ray emission was virtually absent and which were believed to represent regions in which the magnetic field lines extend far out into the interplanetary medium. The holes could be the source of the solar wind, whose relationship to the interplanetary magnetic field is undergoing further intensive study, along with the possible relationship between the interplanetary magnetic-field structure and the Earth's weather.

Studies of Comet Kohoutek

An unplanned bonus resulted during the Skylab mission. Skylab planning was modified to include observations of the new comet Kohoutek, since calculations showed that it would closely approach the Sun about Christmas.

Kohoutek became the best observed comet in history, and its observations contributed a wealth of new knowledge about comets. The third crew took a series of photographs of the comet in visible light with a small hand-held camera. Other photographs made with a French ultraviolet stellar camera gave information useful for determining the gas-to-dust ratio in the comet's coma. After perihelion (the comet's closest approach to the Sun) photographs taken through the coronagraph clearly showed the antitail of the comet, a spike apparently protruding from the side of the comet toward the Sun.

"The comet's got a spike and a tail," Astronaut Gibson gleefully confirmed during an extravehicular activity, "The spike is very evident. It is not 180 degrees out, but more like 160 degrees. It is yellow and orange . . . just like a flame. It seems to be the same distance out as the tail, and there is a diffuse amount of material which goes out and joins up with the tail."

Gibson made a further valuable contribution to these observations through a series of sketches.

The Skylab observations of the comet further proved the great flexibility and adaptability of a manned spacecraft. Even though the Kohoutek project was introduced and prepared on short notice, it was worked into the Skylab mission plan without disrupting other areas.

A Broad View of the Earth

With its precise instruments, the observational capability of its crew, and its coverage of three-quarters of the Earth's surface, Skylab offered an Earth observation capability never before available. In traversing this area, Skylab passed over each point once every 5 days, so that time-based variations on Earth were easily recorded.

The more than 40 000 photographs made of the Earth and the thousands of observations recorded on miles of magnetic tape provided a mass of data, already of great value to those involved in improvements of agriculture and forestry, geological applications, studies of the oceans, coastal zones, shoals

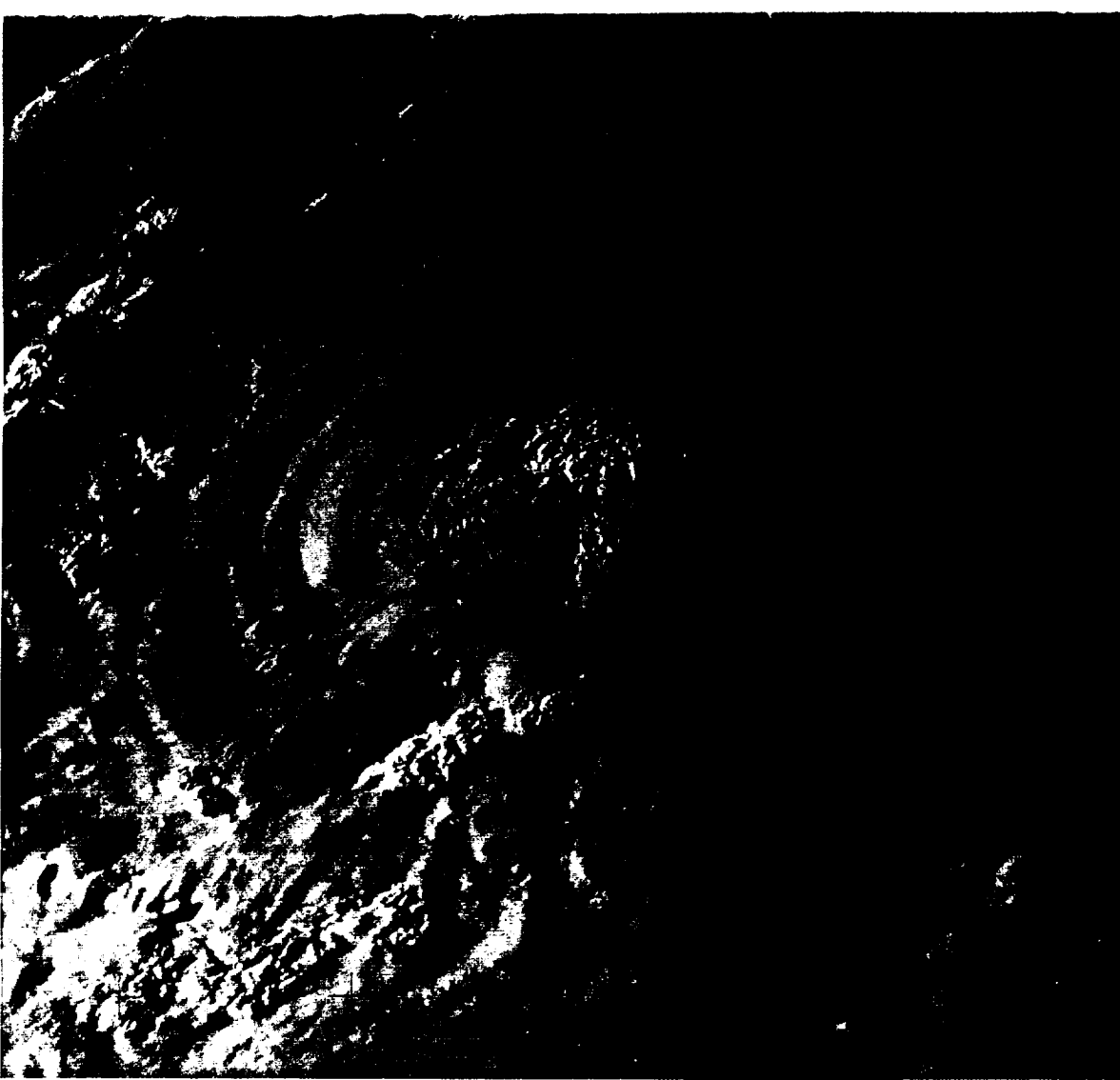
and bays, and continental water resources, investigations of atmospheric phenomena, regional planning and development, mapping and further development of remote sensing techniques.

Materials Processing Studies

The zero-gravity condition existing in Skylab made it possible to perform operations in materials processing that would have been impossible or extremely difficult on Earth. When the opportunity for elaborate and controlled materials processing experiments on Skylab arose, experimenters were quick to prepare a program of studies. Major experiments included crystal formation from vapors; alloy formation from components of different densities; homogeneity of dopant distribution in semiconductors; diffusion in liquid metals; and solidification of molten metals. All of these studies required controlled heating in a specially provided furnace, and subsequent cooling of samples.

Samples had to be selected according to the temperature range offered by the furnace. In one experiment, the front end of a small cylinder of indium antimonide was melted by radiative heat inside a graphite cavity and allowed to resolidify without touching the walls. Under Earth conditions, the semiconductor alloy would have solidified in crystalline form. The crystals, however, would have been limited in homogeneity because of convection currents which disturb uniform crystal growth and cause defects within the lattice structure. The Skylab sample, undisturbed by gravity, crystallized as a very homogeneous single crystal with only very few lattice defects. In fact, the number of lattice defects in the space-grown sample was an order of magnitude smaller than in the best Earth-grown crystals. Even its surface was of a smoothness unobtained in Earth-bound laboratories. This success implies that other semiconductors in all probability will also form crystals of unprecedented homogeneity and size when they are allowed to solidify under zero gravity without wall contact. The availability of such crystals will have a profound effect on the electronics industries.

In another crystallization experiment, germanium selenide was vaporized at the hot end of an ampoule and allowed to condense at the cold end. This process involves a gaseous component, germanium iodide, as transport agent. Under Earth



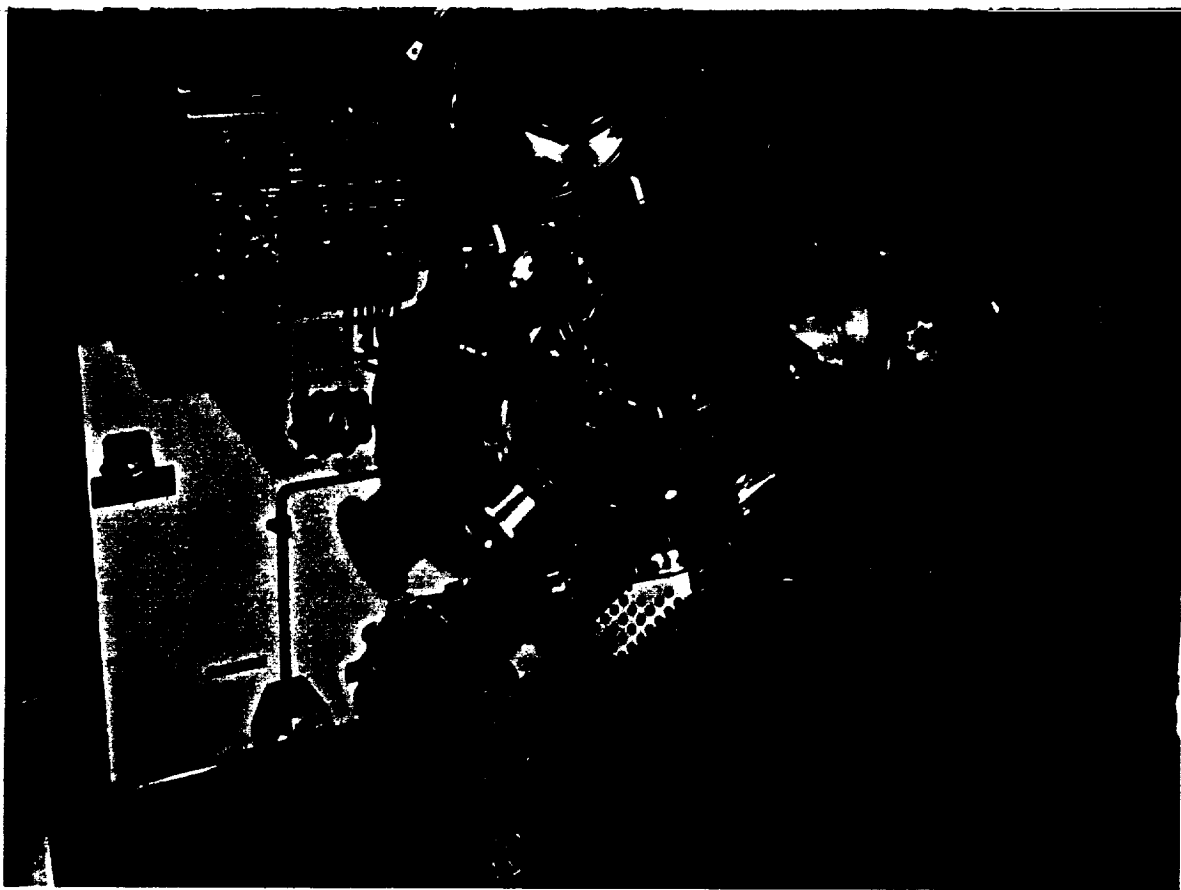
Photographic records, such as this one made of tropical storm Ellen, provide much valuable data for meteorologists.

conditions, crystals forming in this vapor deposition process would remain relatively small; they show signs of irregular growth, caused mainly by convective motion in the gaseous medium. A germanium selenide crystal grown on Skylab exceeded in size that of Earth-grown crystals by a factor of 10, and its surface after cleaning proved to be virtually free from defects. This dramatic improvement of crystal quality by elimination of gravity effects is even more surprising since the experiment was only exploratory in nature, without an attempt to optimize thermal gradient and vapor pressure in the ampoule. The growth rate of the crystal was considerably higher than expected

for a vapor deposition process governed only by diffusion, without convective currents. The reason for this high deposition rate has not yet been established.

A third experiment involved the recrystallization of indium antimonide, doped with tellurium. A sample of this material was prepared on the ground and partially remelted during orbital flight in such a way that the molten part, attached to the solid part by surface tension and cohesion, did not touch any container walls. When samples of this material solidify under gravity, convection currents caused by thermal gradients segregate the dopant, a process which leads to a layered structure of the

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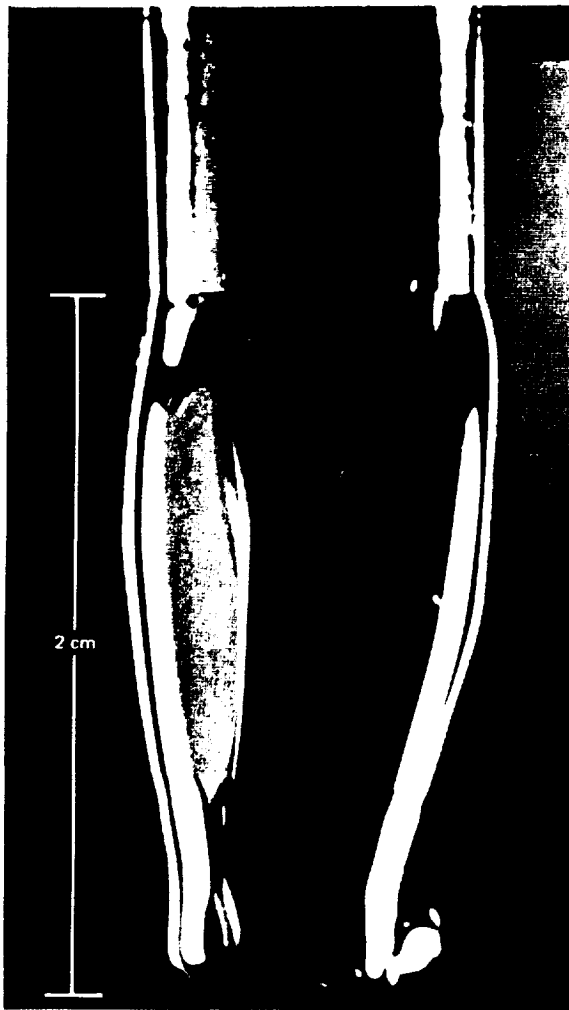


The materials processing facility aboard Skylab was a compact unit which permitted a number of significant experiments to be carried out during the three manned periods.

crystal. This separation of components results in nonuniform electrical conductivity, and in unpredictable semiconductor properties of the crystal. Solidification under the zero-gravity condition on Skylab produced a material in which the striations had completely disappeared. Measurements showed that the electrical conductivity throughout this part of the crystal, with the exception of narrow regions near the edges, was very uniform. This result showed that without gravitational forces, crystals obtain far greater homogeneity than under Earth conditions; ideal steady-state growth in all three dimensions seems to be achieved under zero-gravity conditions. With special precautions in Earth-bound laboratories, such as carefully controlled temperature profiles or strong magnetic fields, the layering of tellurium-doped indium antimonide crystals can also be suppressed to a substantial extent; however, the uniformity of electric properties in space-grown crystals is still superior to that of Earth-grown crystals.

Several of the materials processing experiments on Skylab concerned the mixing and alloying of components which do not form under Earth conditions because gravity forces separate the components before they solidify. Mixtures of gold and germanium, for example, show very coarse dispersion and even large-scale segregation when solidified in Earth-bound laboratories. Samples of gold-germanium mixtures were melted in the furnace on board Skylab. After solidification under zero gravity, the material showed a very fine and uniform dispersion. At some places within the material, small areas were found which obviously represent a composite not formed under gravity, perhaps a new alloy or a compound. When irradiated with X-rays, these areas emitted characteristic X-ray lines which had not been known before.

Each of the 14 experiments in the Skylab materials processing program was successful in demonstrating some decisive influence of gravity upon processes that are essential in the formation



This indium antimonide crystal grown aboard Skylab indicates the intrinsically high quality that space manufacture of crystals can produce.

of materials. The results of most experiments substantially exceeded the expectations of the experimenters.

All experiments dealing with materials in space convincingly proved that the weightless environment of orbital flight indeed offers to the materials scientist highly useful tools unavailable on Earth, but full of promise for further experimentation and discovery.

Student Experiments and Science Demonstrations

The student experiments provided a unique opportunity for a large number of high school students to participate in spaceflight activities as well as to pursue areas of scientific research. Although not all experiments worked as expected,

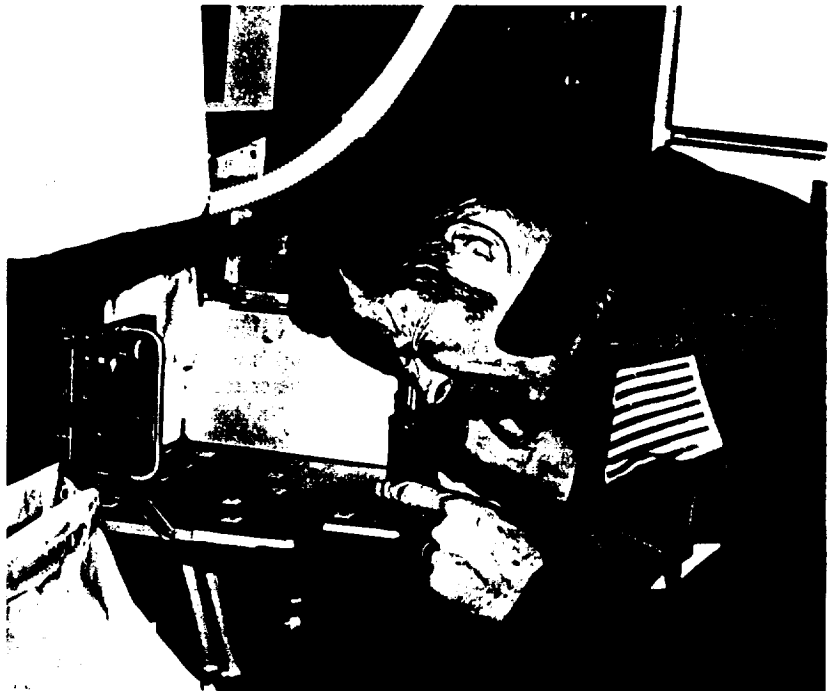
they were a successful and very rewarding part of the program. Biologists were further enlightened on the adaptive processes of life in a weightless environment when two spiders wove webs of a quality approaching those they made on Earth. Similarly, another student experiment provided valuable new data on the neutron flux within space.

The science demonstrations performed by the astronauts also proved to be successful as well as educational. Some provided valuable new data on the behavior of liquids in the absence of gravity. Films of the demonstrations have been made available to science teachers as training aids.

Earth-bound Man's Capabilities Extended

Skylab was, essentially, a means of extending man's observational capabilities. It permitted him to make scientific observations of the solar system without interference from Earth's atmosphere. It

Experiments proposed by high school students in a nationwide competition were carried out during the three manned periods. Here Kerwin studies the growth in space of bacteria and spores.





Joe Kerwin, the first scientist pilot, established the feasibility of performing a science demonstration using free-floating globules to investigate the damping of fluid oscillations, surface tension, coalescence of raindrops, and the general properties of fluids in the absence of Earth's gravity.

made possible a broad view of the planet Earth denied him by other available means, and it allowed him to make comparisons and judgments as he viewed earthly features. And it allowed him to escape the gravitational influences felt on Earth to conduct biomedical and space processing experiments, possible only in the space environment.

Man, therefore, became not only the reason for Skylab, but also a vital element in the conduct of the Skylab mission. Astronaut Gibson summed it up reflecting on solar observations:

"The success of the . . . missions depends to a large extent on the scientific knowledge, training, and decision-making capabilities of both the astronauts and the ground support team. The opportunity to exercise scientific judgment during flight and to enhance significantly the value of the data

returned arises directly from the nature of the solar observations. We are close enough to the Sun to see much detailed structure in its atmosphere. Because of the complexity of this structure and the wide range that has been observed in its characteristic time for change (from many years down to seconds) a wide variety of observations is possible. Thus, decisions must be made which determine the amount of new and significant information in the returned data.

"The role of the onboard observer can be simply stated. He is presented with television pictures of the Sun at several wavelengths in the electromagnetic spectrum, as well as with other indicators of the state of solar activity. Instruments which are capable of high data-acquisition rates and which can be operated to observe only a small portion of



Operation of the Earth resources cameras required much attention by the flight crews. Their ability to select targets for observation was invaluable.

Skilled operators were required for much of the experimental equipment. Astronaut Bean is shown obtaining stellar ultraviolet spectra.





Some pastimes were considerably different from those enjoyed on Earth, but reading was a popular diversion. Here, Bean relaxes in his sleep restraint as he reads.

the Sun are available for use by the observer. However, he is constrained by limited quantities of photographic film in all but one of the instruments. Hence, the scientific value of the returned data is dependent upon the ability of the onboard observer to make judicious decisions concerning when, at what rate, and from where on the Sun to take data with each instrument."

Alter Ego of the Principal Investigator

All of Skylab's crewmen received several years of flight training. Much of it related to operations of the spacecraft, but about an equal fraction was devoted to experimental objectives in trainers and simulators, on some occasions with a principal investigator working alongside. In a few cases, such training was conducted in the laboratory of the principal investigator. The result was the establishment of a close rapport between flightcrews and the ground-based scientific staff, which greatly increased mutual confidence and the ability to work together to achieve the experimental objectives.

One example of this cooperative effort was the development of scientific shopping lists which were devised after the first manned period. These lists allowed the crewmen to work independently of ground advice in selecting targets and objectives for the solar observations. The lists were originally devised to suggest to the crewmen a variety of short objectives that could be met if an extra 5 or 10 minutes of observing time should become available. The data collected in those intervals were so useful that the scientists began requesting specific allotments of time to be used entirely at the crewman's option. "In this activity," according to Astronaut Garriott, "the crewman truly performed as the alter ego of the solar science community."

Scientists Laud Skylab Program

Scientists in various disciplines, some of whom had reservations about the program initially, had a great deal of praise for Skylab after its successful mission.

In speaking of experiments in growing crystals aboard Skylab, Harry C. Gatos, Massachusetts Institute of Technology, said, "Understanding solidification processes and achieving crystalline perfection and chemical uniformity will without

doubt usher in a new era in materials processing, leading to materials that can be used at their theoretical performance, rather than at hundreds of thousands of times below that."

John T. Shepherd, Director of Research at the Mayo Clinic, Rochester, Minn., reported at the Skylab Medical Experiments Symposium: "The wealth of data which has been accumulated on the adjustments of man to space travel ... truly establish his future role in the exploration of the universe." J. R. Hordinsky, of the Johnson Space Center, provided the following summary: "The medical experiments data analyzed to date and the observations made during and after the flight do not indicate any major medical constraints for continued extension of man's duration in space. . . . The Skylab crewmen demonstrated that man can fully adapt to a weightless environment, perform in an efficient and effective manner, and then readapt to the one-g environment. A major milestone in the manned spaceflight program has been accomplished."

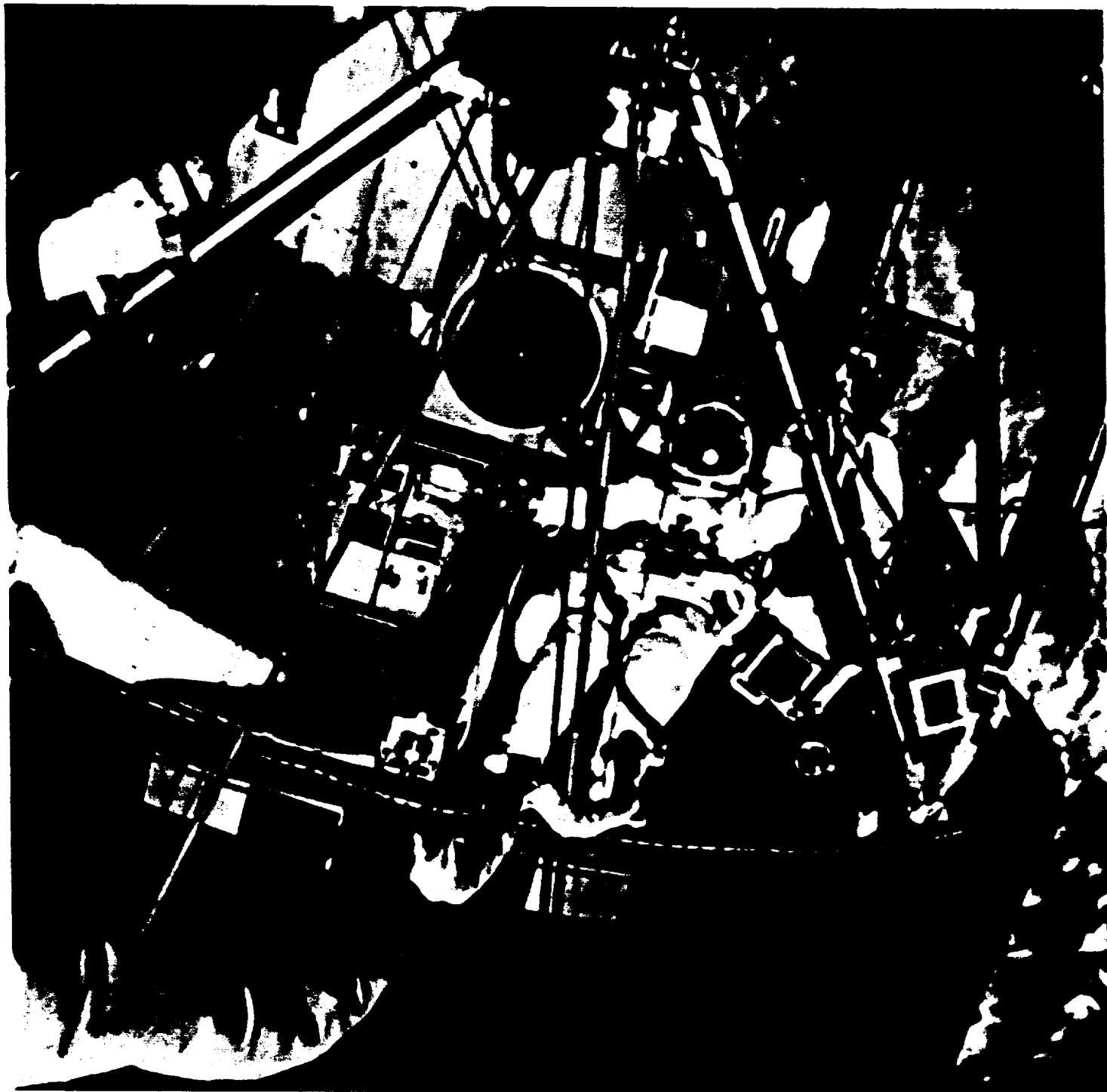
Herbert Friedman, of the E. O. Hulburt Center for Space Research, Naval Research Laboratory, commented upon the completion of the Skylab mission: "The Skylab ATM [Apollo Telescope Mount] observations may upset many long-cherished ideas of solar physicists. Achieving finer detail in geometry and spectral resolution than ever before, ATM probed the solar atmosphere from the lowest photospheric level to the far reaches of the corona. . . . It marks a new revealing of the Sun, and the opening of a neoclassic period of solar studies linked with the much-anticipated shuttle sorties of the 1980's."

Perhaps the most significant comment concerning man's role in the scientific exploration of space, as demonstrated in Skylab, was that of Leo Goldberg, Director of Kitt Peak National Observatory, who said:

"Many of us had serious doubts about the scientific usefulness of men in space, especially in a mission . . . which was not designed to take advantage of man's capability to repair and maintain equipment in space. But these men performed near miracles in transforming the mission from near ruin to total perfection. By their rigorous preparation and training and enthusiastic devotion to the scientific goals of the mission, they have proven the value of men in space as true scientific partners in space science research."







MISSION SUMMARY

Manned periods	First	Second	Third	Total
Launch	5/25/73 9:00 a.m. EDT	7/28/73 7:10 a.m. EDT	11/16/73 9:01 a.m. EDT	
Splashdown	6/22/73 9:49 a.m. EDT	9/25/73 6:19 p.m. EDT	2/8/74 11:17 a.m. EDT	
Duration (day:hr:min)	28:0:49	59:01:9	84:01:16	171:13:14
Revolutions	404	858	1214	2476
Distance (million miles)	11.5	24.5	34.5	70.5
SEVA ^a	0:37 (5/25/73)			
EVA ^b 1 duration (hr, min)	3:30 (6/7/73)	6:29 (8/6/73)	6:33 (11/22/73)	
EVA 2 duration (hr, min)	1:44 (6/19/73)	4:30 (8/24/73)	7:01 (12/25/73)	
EVA 3 duration (hr, min)		2:45 (9/22/73)	3:28 (12/29/73)	
EVA 4 duration (hr, min)			5:19 (2/3/74)	
Total EVA	5:51	13:44	22:21	41:56
Solar observatory photos	30 242	77 600	75 000	182 842
Earth resources photos	8886	14 400	17 000	40 286

^aStandup (in spacecraft hatch) extravehicular activity.

^bExtravehicular activity (completely outside of spacecraft).

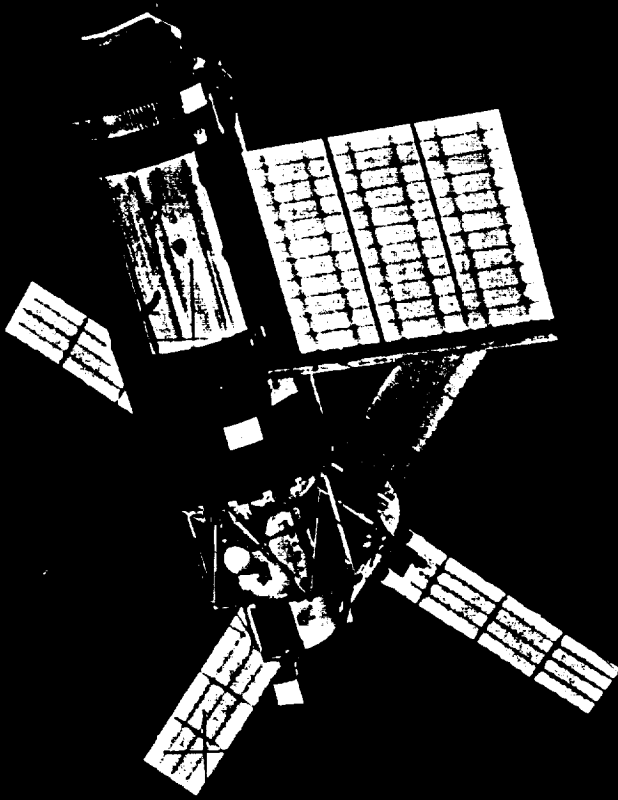
EDITOR'S NOTE

Skylab's unprecedented success is a tribute to the space activities of the past in that it was a direct product of the technology, design concepts, ground and flight hardware, facilities, and experienced team of people from earlier programs and activities. This vast resource of knowledge and experience, coupled with the commitment to establish a space station of significant size and capability, enabled NASA and the related organizations—industry, government, and universities—to produce exciting results in engineering, physics, astronomy, earth resources, biomedicine, and space processing far greater than had ever been anticipated.

One of a series of books devoted to the Skylab program, this volume presents the dramatic story of Skylab's design, development, launch, and successful operation. In the preparation of this book, guidance and technical counsel were provided by a NASA Editorial Board for which Robert E. Pace, Jr., served as Managing Editor. Other members were John A. Chambers, William B. Chubb, Robert G. Eudy, Carlos C. Hagood, George B. Hardy, Richard T. Heckman, George D. Hopson, James E. Kingsbury, Jerrol W. Littles, Richard A. Marmann, John D. Stroud, Arnold D. Aldrich, Thomas R. Loe, and Walter D. Wolhart. Their outstanding contribution to the program qualified them as authoritative technical consultants in the preparation of this volume. The manuscript was prepared by Clinton Scott, John C. Goodrum, Mitchell R. Sharpe, and Harry R. Melson.

This volume is offered in recognition to those dedicated thousands who contributed their skill and knowledge to the success of Skylab. The wealth of information obtained during man's longest journey into space has provided the answers to many questions, as well as revealing new questions and knowledge, about the Sun, the Earth, space, and man himself. An adventure of today, Skylab was also an investment in tomorrow. Its results are a legacy for all, forever.

Leland F. Belew
Skylab Program Manager
Marshall Space Flight Center





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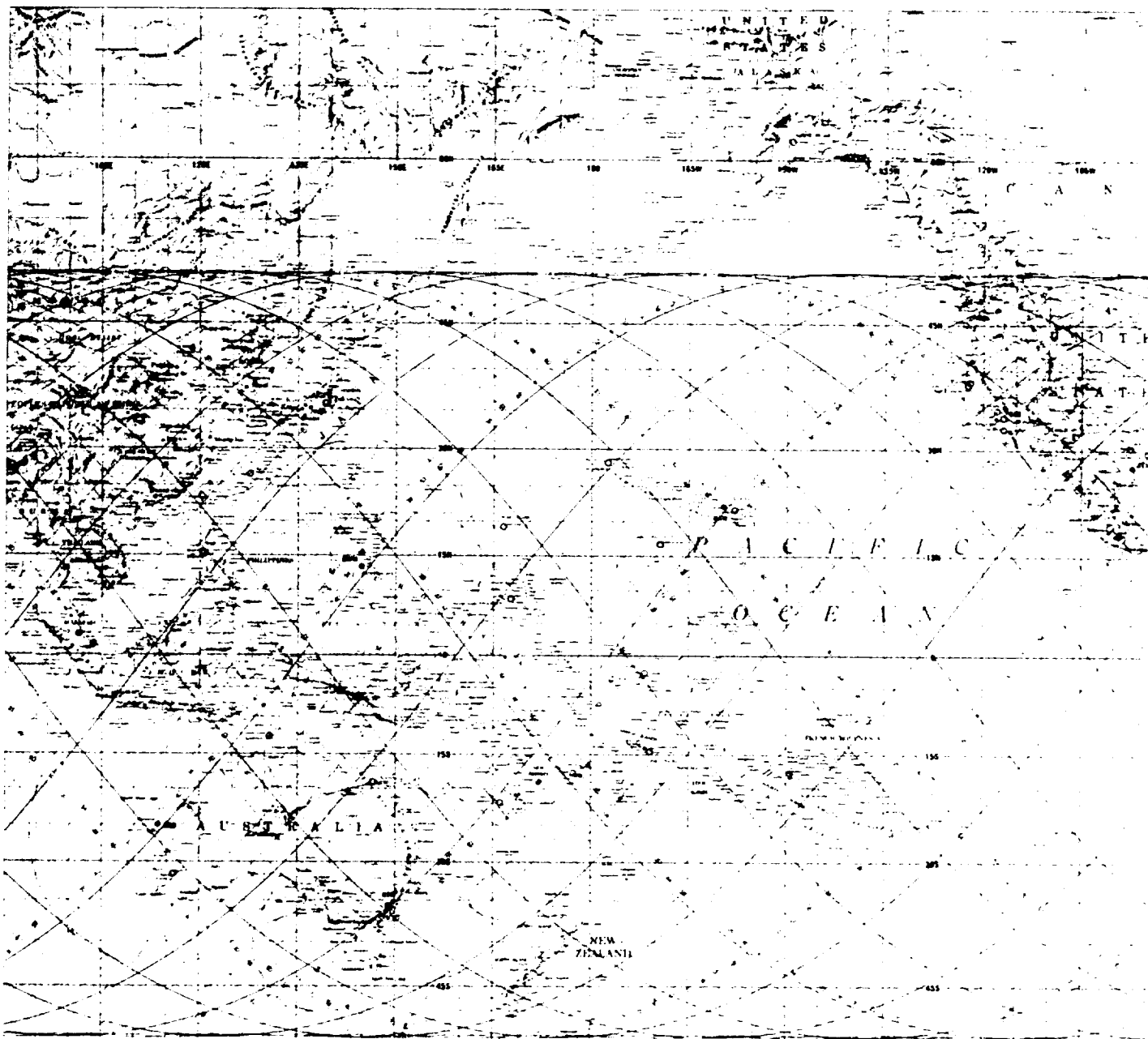
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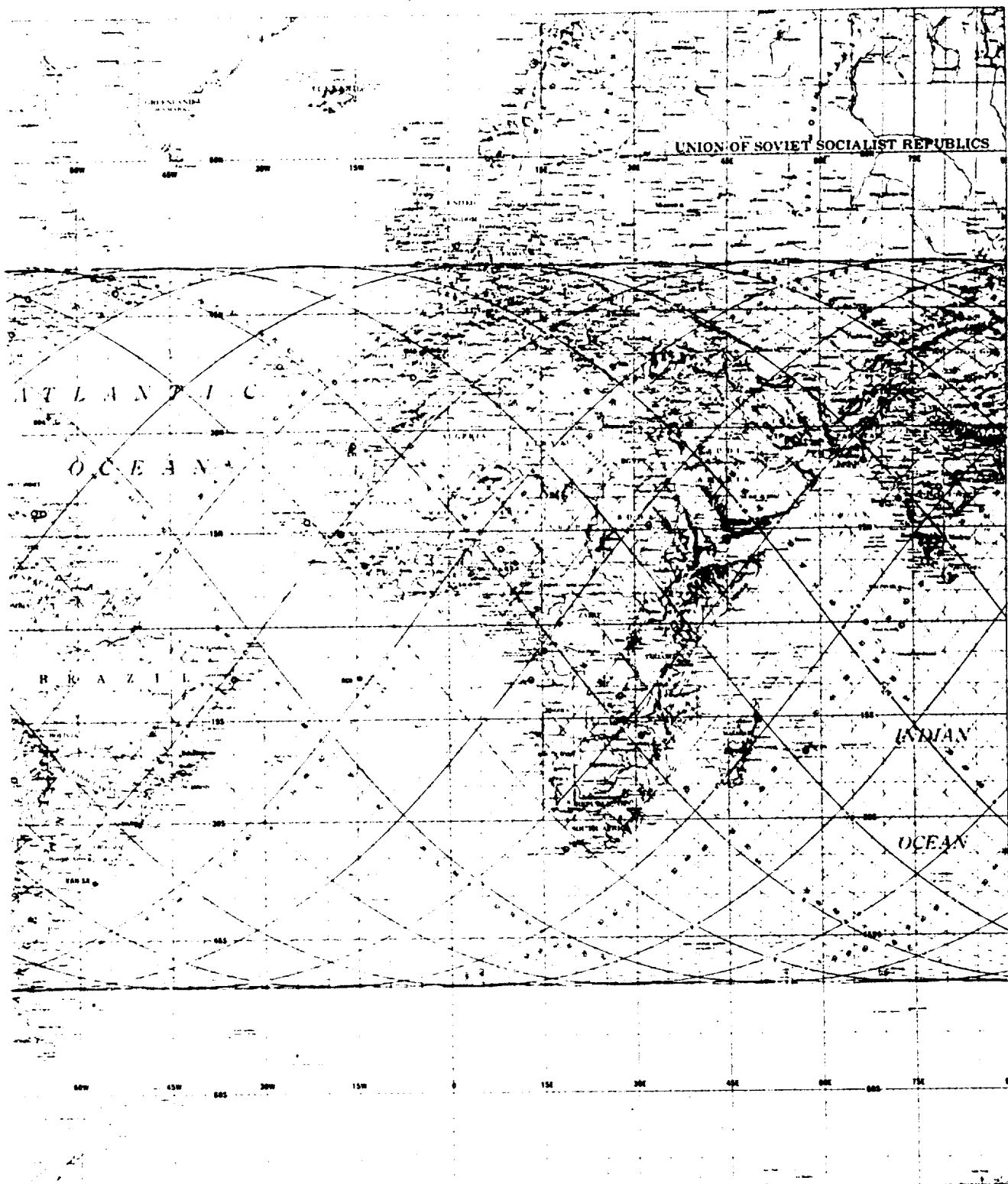
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